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GUIDE TO DESIGN OF ELECTRONIC EQUIPMENT FOR MAINTAINABILITY

JOHN D. FOLLEY, JR. AND JAMES W. ALTMAN

AMERICAN INSTITUTE FOR RESEARCH

APRIL 1956

WRIGHT AIR DEVELOPMENT CENTER

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AERO MEDICAL LABORATORY
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WADC TASK 71502

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This report was prepared by the American Institute for Research under Rome Air Development Center Project Number 7502 entitled: Human Engineering of Equipment for Maintenance Efficiency, Wright Air Development Center Task 71502 entitled: Guide to Human Engineering of Electronic Equipment for Ease of Maintenance. The project was administered by the Psychology Branch, Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, with Dr. Gordon A. Eckstrand serving as Project Engineer.

Users of this report are invited to submit to the Psychology Branch comments which would be useful in adding to or revising material contained in this document.

This report has been released to the Armed Services Technical Information Agency, Knott Building, Dayton 2, Ohio. It has also been released to the Office of Technical Services, Department of Commerce, Washington 25, D. C. for sale to the general public.

The authors are especially grateful to Dr. Eckstrand for his interest and many helpful suggestions. Acknowledgment is also due Dr. Robert B. Miller who served as Principal Investigator on the project. Mr. Wesley Rohrer worked out the examples of job aids presented in Section 5.

Space prevents individual acknowledgment of the efforts of the many other contributors to the guide. Mention must be made, however, of the scores of Air Force electronic technicians who provided much of the data on which the specific recommendations are based. A very special thanks is due to the sixty or so reviewers who contributed so generously of their time, experience, and knowledge in criticizing previous versions of the guide and suggesting improvements.

ABSTRACT

A major problem faced by the military services is effective maintenance of complex electronic equipments despite shortages of highly skilled maintenance technicians. This guide is intended to help alleviate this problem by recommending design practices which will maximize the ease with which electronic equipments can be maintained. Factors to be considered in planning for maintainability are briefly reviewed. A schedule of steps to be taken in designing a maintainable system is presented. Specific characteristics are recommended for equipment and maintenance procedures.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

for JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

Table of Contents

section 1

Introduction to the Guide

Manuscript released by the author 30 April 56 for publication as a WADC Technical Report.

WHY THE GUIDE WAS WRITTEN

This guide was written to provide principles to be applied during electronic equipment development for "building in" provisions for more effective maintenance.

It is intended to help minimize maintenance difficulties which in the past have resulted from inadequate consideration of maintenance needs and capabilities and limitations of maintenance personnel.

The basic premise of the guide is that relatively small expenditures of time and money for maintainability will produce much larger savings in maintenance costs.

INTENDED AUDIENCE

This guide was written for all persons who have an important role in designing maintainable electronic systems for the Air Force.

All such individuals are referred to as "designers" in this volume.

"Designers" include those who:

1. Specify the required characteristics of prime equipments or maintenance supports such as test equipment, tools, and maintenance instructions.

2. Develop prime equipments or maintenance supports.

3. Monitor the development of equipments or maintenance supports.

4. Perform engineering or operational suitability evaluations or decide whether a given system should be accepted for operational use.

LIMITATIONS OF THE GUIDE

Many recommendations in this guide are "rules of thumb." Some are not yet supported by adequate research data because human engineering for maintenance is new and relatively undeveloped.

The guide will not provide answers to all problems in designing for maintainability. There will be many instances in which the designer will have to make specific decisions based on incomplete information.

SCOPE OF THE GUIDE

Two aspects of maintenance may be defined:

> Maintainability is a function of the rapidity and ease with which maintenance operations can be performed to help prevent malfunctions or correct them if they occur.
>
> Reliability is the probability that a product will give satisfactory performance for a given period of time when used in the manner and for the purpose intended.

This volume deals with maintainability, not reliability. Maintainability may, however, affect the reliability of a system. For example, reliability will be reduced if preventive maintenance is inadequate.

This guide is concerned with design features which affect preventive and corrective maintenance of ground and airborne electronic systems. Maintenance includes inspecting, checking, trouble shooting, adjusting, replacing, repairing, and servicing. The factors of supply, selection and training of maintenance personnel, physical facilities for maintenance and provisions for modification also affect maintainability. Detailed recommendations on these factors are not included in this guide.

MAINTAINABILITY VERSUS PERFORMANCE REQUIREMENTS

Maintainability requirements for electronic equipment have been extremely vague as compared to the detailed performance requirements usually specified. Insignificant performance requirements have sometimes been met by design of trick circuits or unusual components which have increased maintenance difficulties. Specific recommendations for maintainability should encourage the contractor and the Air Force to work out satisfactory compromises between maintainability and performance requirements.

ORGANIZATION OF THE GUIDE

The major sections of the guide are:

Section 1. Introduction to the Guide

Section 2. Factors in Planning for Maintainability

Section 3. A Design Schedule for Maintainability

Section 4. Recommended Characteristics for Maintainable Equipment

Section 5. Recommended Characteristics for Maintenance Procedures and Job Instructions

section 2

Factors in Planning for Maintainability

Overview of Factors in Planning for Maintainability

In planning effectively for maintainability, the designer must:

1. Integrate the design of all maintainability supports to insure compatibility.

2. Take into account personnel capabilities and limitations.

3. Allow for difficult field conditions.

4. Coordinate his efforts with others in the development sequences.

Each of the four subsections which follows presents recommendations concerning these factors.

MAINTAINABILITY SUPPORTS

Planning for effective design requires systematic consideration of the maintainability supports shown below.

Prime Equipment

Unless the prime equipment is itself maintainable, all other maintenance design is useless. Design of prime equipment for maintainability should include:

1. Self-checking features or test points available for checking by auxiliary equipments. These test features must permit trouble shooting down to each replaceable or repairable portion of the system at each maintenance level.

2. Easy access to and identification of test points and equipment units.

Test Equipment

Functions of the prime equipment not self-checking must be checked by auxiliary test equipments. These test equipments must be provided for all levels of maintenance.

Maintenance Procedures and Diagrams

Effective maintenance requires that procedures and diagrams be an integrated part of equipment development. They should be available when the equipment first must be maintained.

Tools

Required special tools should be designed simultaneously with the prime equipment; necessary common hand tools should also be specified.

Maintenance Personnel Requirements

The equipment designer is in the best position to provide information needed for training maintenance technicians prior to use of the equipment. This advance training permits effective maintenance from the time the equipment first enters the field.

Work and Storage Facilities

Design of the equipment and auxiliary materials, such as test equipment, has a strong effect on the facilities required. Unless the designer provides adequate advance information, construction of these facilities must wait until the equipment is available. This delays achievement of a satisfactory maintenance capability.

Provisions for Supply

Equipment designers should take an active role in working with the Air Materiel Command so supply channels will be ready and provided with spares when the equipment goes into operation.

Overhaul Facilities

The equipment manufacturer should coordinate his plans for overhaul with the Air Materiel Command and operating commands so that minimum waste and confusion will result from integration of new equipment into the Air Force.

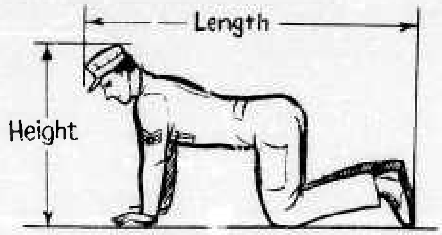
Modification Concept

Coordination by manufacturer, Air Materiel Command, and Air Research and Development Command will minimize both the number of modifications and the disruption of maintenance operations resulting from necessary changes.

Installation

Close coordination of equipment design features and characteristics of the proposed installation is required throughout development to insure a maintainable system.

PHYSICAL DIMENSIONS OF MAINTENANCE PERSONNEL[1]

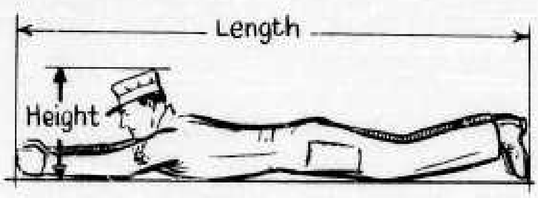


Minimum length required for crawling:

59 inches

Minimum height required for crawling:

31 inches



Minimum length for working in prone position:

96 inches

Minimum height for working in prone position:

17 inches

Maximum allowable depth of reach:[2] 23 inches

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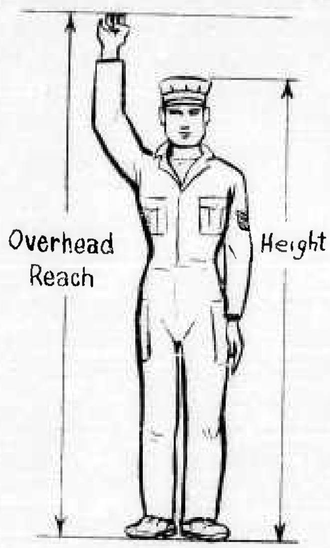
1. Data furnished by the Anthropology Section, Biophysics Branch, Aero Medical Laboratory, Wright Air Development Center. (These data are also presented in Reference 11.) Data are from 40 male subjects, average age 24.4 years. Dimensions given should make the equipment suitable for 95% of technicians. The measurements were taken on nude subjects; clothing was added by the present authors for purposes of illustration. Subjects wearing clothes would have slightly larger dimensions than those shown.

   Additional data on body measurements are presented in Hertzberg, Daniels, and Churchill (Reference 3); Woodson (Reference 8); and the Tufts Handbook (Reference 10).

2. Based on informal measurements by authors.

Maximum allowable overhead reach:

76 inches

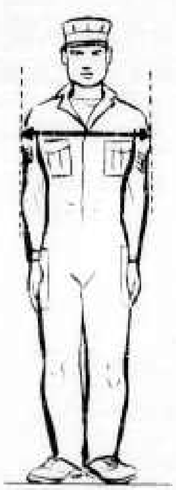


Minimum overhead height for standing position:

73 inches

Minimum dimension for passing body width:

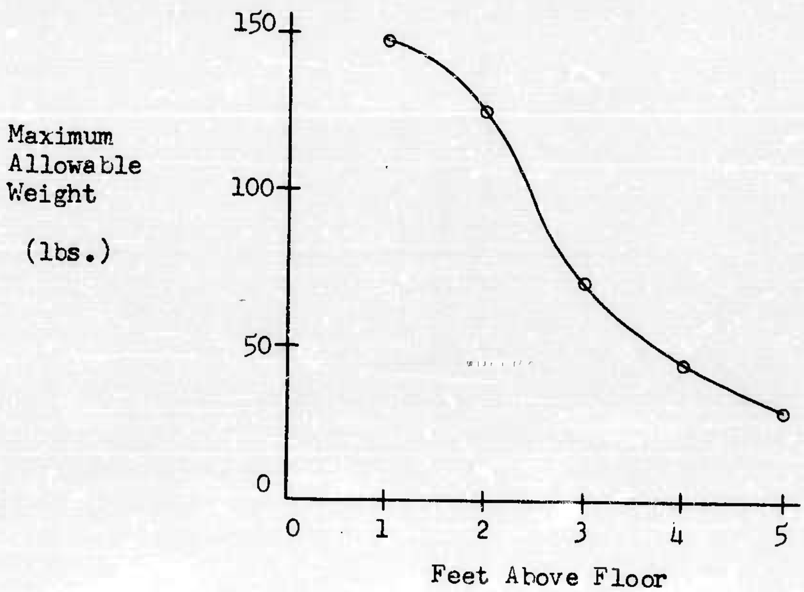
20 inches



Minimum dimension for passing body thickness:

13 inches

WEIGHT LIFTING CAPACITY[1]



Caution: These weights are absolute maximums for lifting a unit of convenient size and shape with unlimited work space.

Design should aim for much smaller weights to account for realistic work conditions.

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1. Unpublished data furnished by Anthropology Section, Biophysics Branch, Aero Medical Laboratory, Wright Air Development Center. Data are from 19 male subjects; average age 21.6 years, average weight 161.2 pounds, average height 69.5 inches. Ninety five per cent of technicians should be able to lift these weights under the conditions specified.

MAINTENANCE SKILLS OF TECHNICIANS

The skill level of maintenance technicians is important to the equipment designer since equipments demanding skill levels higher than those available will not be maintained successfully.

Technicians cannot be assumed to have a high level of interest or previous work experience in electronics. About all that can be expected is in-service training and some high school education, not necessarily graduation.

Maintenance supervisors report that technicians are able to perform only simple maintenance tasks when they complete their training. Consequently, much on-the-job training is usually required. The short average length of enlistments resulting from low re-enlistment rate leaves little time for technicians to achieve high job proficiency.

One result of this situation is that technicians more frequently make errors on the job than more experienced personnel. For example, they have been reported to use hand tools for wrong purposes; damage equipment by switching to wrong ranges; not follow checklists; handle components carelessly; and replace units without locating a malfunction. Designs directed toward reducing the likelihood of occurrence of these errors will improve over-all system performance.

<u>Conclusion</u>: It may be necessary for the designer to "build in" features for maintenance that would not be required if he were maintaining the equipment himself. Specific recommendations for such features are in Sections 4 and 5. A procedure for incorporating these recommendations during equipment development is suggested in Section 3.

MAINTENANCE CONDITIONS TO CONSIDER IN DESIGNING FOR MAINTAINABILITY

The designer must be aware of the many conditions in the field that affect maintainability if he is to design equipment that is compatible with them. Since most design engineers have limited opportunity to observe maintenance operations first hand, some of the more important conditions are listed below.

Conditions for Operator Maintenance

It is obvious that in interceptor and fighter aircraft the operator cannot leave his seat to perform maintenance. This is becoming increasingly true of bomber aircraft.

The operator must frequently take over the functions of malfunctioning portions of a system. Weight and space limitations usually prohibit duplicate circuits for standby.

The amount of training in maintenance procedures that can be given all operators is severely limited.

The operator may be working under high combat stress, traveling at high speed, and be encumbered by a parachute, "Mae West," and pressure suit when maintenance is required.

Conclusion: The designer must provide the operator with signals that clearly indicate malfunction, and with unambiguous instructions for action that will compensate for the malfunction.

Conditions for Line Maintenance

Method of work assignment:

Assignments may be spoken or written. Trouble-shooting assignments sometimes are very general, such as "radar out."

Use of Technical Orders:

Technical Orders are seldom used directly in line maintenance because technicians feel that they are too bulky or too hard to understand. Technicians sometimes make up their own checklists, or perform maintenance tasks from memory.

Tools and test equipment:

Required tools, particularly special tools, are sometimes not available.

Shortages of test equipment occur. Examples have been observed of partially damaged test equipment being kept in operation because sending it to the depot for repair would take too long, and replacements were not available.

Test equipment accuracy is not always dependable. Calibrations are infrequent and sometimes as informal as comparing, for example, one voltmeter with another of the same model.

Ground power units are not always available in sufficient quantity; when they are used, their engine noise makes communication between technicians difficult.

Working conditions:

Extremes of lighting may be encountered, varying from working in almost total darkness with only a flashlight, to bright sunlight reflected from the aircraft skin. Even in bright daylight the equipment may be located in dark corners or areas making it particularly difficult for the technician to see details because his eyes are not adapted to the darkness.

Temperatures range from sub-zero to tropic heat. Working in a body position which may be only mildly uncomfortable in moderate temperature may become almost intolerable in a few minutes of extreme heat. Perspiration makes the technician's hands slippery so that objects will tend to slip from his grasp. In low temperatures, stiff fingers make fine movements very difficult and make the technician tend to drop tools and equipment.

Weather changes can delay line maintenance operations on aircraft which are not protected. If access panels are open and rain starts, maintenance activities have to be suspended and the equipment quickly covered to prevent its getting wet. In a season of sudden brief showers long delays may occur in performing maintenance jobs.

Radio and radar interference from nearby equipments sometimes clutters check indications.

There is usually very little room for technicians to spread out diagrams, instructions, and tools.

In addition to the above conditions, line maintenance is frequently performed under severe time stress as a result of operational requirements.

Conclusion: Conditions for line maintenance are more severe than for other levels. Consequently, the designer should give special emphasis to designing for maintainability at the line level.

Conditions for Shop Maintenance

Incompatibility between the extent of maintenance specified and provisions for accomplishing this maintenance cause much difficulty in accomplishing shop maintenance. Shop personnel frequently lack information, tools, test equipment, or spare parts needed to accomplish the maintenance expected of them. Physical factors such as temperature, lighting, or space seem to be relatively less important.

Conclusion: The designer must provide a complete description of facilities and equipment required to accomplish specified shop maintenance. Sending units to the depot which could be repaired at the shop level clogs supply channels and increases equipment down time for repairs.

Conditions for Periodic Maintenance

Conditions for periodic maintenance tend to include both those for line and those for shop maintenance. Periodic maintenance may include both functional checks and inspections for physical damage. Checks and inspections may be made on installed equipments or the equipments may be removed from installation as part of the periodic maintenance.

Conditions for all Levels

A shortage of qualified personnel to perform maintenance is reported by supervisors as the chief problem in getting maintenance done. Maintenance officers have reported that only a small proportion of assigned personnel are able to perform adequate maintenance without close supervision. In most cases the primary complaint was that the personnel were unable to do the job rather than that not enough personnel were available.

Delays encountered in ordering components or parts may vary from a few hours to several weeks or months.

Shortages in supply lead to cannibalization of mock-ups to keep operational equipment in satisfactory condition. Because the mock-up is used as an important test instrument, putting it out of commission tends to reduce the effectiveness of the maintenance on the operational systems.

Implications for the Designer

Conditions in the field make maintenance difficult even with good design for maintainability.

The designer must therefore make certain that the design of his system for maintainability is the best that can be achieved. Inadequate maintainability may make it impossible for maintenance activities to keep up with operational requirements.

COORDINATING DESIGN FOR MAINTAINABILITY

Importance of Effective Coordination

Inadequate coordination during design has resulted in serious difficulties in designing for maintainability. Critical test points have been left out of plans without the project engineer being informed. Aircraft configuration changes affecting electronic equipment have been made without the electronic system contractor being informed. Electronic system contractors have changed size, weight, and shape of the equipment without informing the aircraft designer, and operating characteristics have been changed without informing test equipment engineers.

The designer can minimize problems of this kind by following the recommendations in this guide.

Responsibilities in Coordination

Individual Design Engineers

Each design engineer must assume responsibility for designing his portions of an electronic system in accord with the general principles in this guide. He must coordinate this design with the total system design. This is not to say that each design engineer should assume the responsibility for coordinating the maintainability characteristics of the total system. It does mean that each design engineer should obtain enough information to assure that the maintainability characteristics of his portion of the system are compatible with the total design of the system. He should also keep others informed concerning those maintainability characteristics of his portion of the system which might affect design of other portions. Remember -- the system includes all of the maintainability supports, not just prime equipment.

Maintenance Design Specialists

Assignment of maintenance design specialists to development projects in advisory and/or decision-making capacities is desirable. Such specialists can coordinate the needs of the operating command with the work of the prime contractor, electronic equipment contractors, Air Force project offices, and the various Air Force human engineering laboratories. They can also coordinate maintainability considerations to ensure that maintainability requirements are being met at each phase of the on-going system development.

Techniques for Coordination

Coordination Conferences

Conferences should be held at regular and stated intervals. Additional conferences can be held whenever major decisions affecting maintainability must be made between scheduled conferences. It is expected that few conferences will be devoted exclusively to maintainability of the equipment being designed, but maintainability considerations should be adequately represented in agenda and in conference personnel.

Each person whose work will be affected by decisions reached or who should undertake action on the basis of decisions reached should receive a copy of the conference report. This does not mean that each draftsman or factory worker whose work might be affected by the conference should receive a conference report. It does mean that someone up the chain of command should receive the report and be responsible for transmitting appropriate information to the proper individuals at the time needed in order for them to carry out the decisions effectively.

Limitations of conferences: Conferences aid coordination by permitting rapid interchange of technical information and judgments of experts in various areas. Conferees must remember, however, that all points of disagreement and all decisions are not best resolved by vote. In technical areas such as engineering or designing for maintainability, deferring some decisions until even a small amount of empirical data can be collected may be the best approach to the problem. In other cases, relying on the judgment of experts in the area may be the best solution.

Periodic Reports

Maintainability should be an integrated part of almost all periodic reports. It is extremely wasteful to begin maintainability design after engineering design has reached advance stages. When this occurs, there are likely to be two types of unfortunate results:

1. Imperative maintenance needs are met by time-consuming and costly redesign.

2. Many desirable maintainability features are not incorporated in the equipment design because they would require expensive retrofit. These features may have cost very little if they had been incorporated in the original design.

One way to ensure that maintainability design is not "too little and too late" is to have persons responsible for maintainability design prepare a section in each periodic report reviewing progress on maintainability design and emphasizing the way in which it parallels the basic equipment design.

When Coordination is Required

In addition to other coordination requirements, agencies involved in equipment design should <u>send out</u> information to other agencies whenever:

1. Decisions are made which affect maintainability design.

2. Information is obtained which augments or supercedes maintainability information previously disseminated to other agencies.

3. An important phase of maintainability planning or design has been completed.

4. Any deviation from previous maintainability planning is contemplated.

Agencies should request information from other agencies whenever:

1. Any other agency has not provided complete information concerning aspects of maintainability design for which it is responsible.

2. A major phase of maintainability design or a major decision concerning maintainability is to be undertaken. This will usually be a request for confirmation of information previously obtained.

section 3

A Design Schedule for Maintainability

OVERVIEW OF THE DESIGN SCHEDULE

This schedule is intended to help the designer effectively build maintainability into the system during its development. The steps to be taken at each stage in the developmental cycle are suggested. The cycle given here is necessarily generalized because the developmental history of each system is unique in some respects.

A summary is given of the steps to be taken at each developmental stage; then each step is taken up individually and the substeps for accomplishing each are spelled out.

All of these equipment development stages may not be carried out in the development of a particular weapon system. In such cases all of the steps in designing for maintainability should still be accomplished, to the extent that this is possible. The "designing" steps in particular should be fitted in, even if some of the steps for testing the maintainability must be omitted.

Special emphasis is given to maintainability considerations in designing the developmental model, since it is at this stage in development that a great many virtually irreversible decisions are made affecting maintainability.

GENERAL PRINCIPLES IN DESIGNING FOR MAINTAINABILITY

Decisions on maintainability must be made before or during design of the developmental model. Changes in design after that are usually judged too expensive or time consuming, and maintainability suffers.

Review the implications of each decision before it is made final. Only in this way can all maintainability requirements be kept reasonable. Every decision concerning maintainability affects almost every other decision.

Coordinate all decisions with other designers or agencies. Each part of the system has to be compatible with the parts being developed by others.

SUMMARY OF STEPS IN DESIGNING FOR MAINTAINABILITY

Stage of Equipment Design	Steps in Designing for Maintainability
Preparation of Planning Documents.	1. Prepare realistic objectives for maintainability.
Study of previous systems.	2. Review experience on previous systems for application to maintainability of new system.
Development of breadboard and experimental models.[1]	3. Establish adjustment points and self-compensating features.
Design of developmental model.[1]	4. Determine maintenance levels. 5. Divide equipment into units. 6. Prepare maintenance procedures. 7. Determine requirements for maintenance supports. 8. Review and modify design for maintainability. 9. Translate design for maintainability into actual equipment and maintenance instructions.
Testing of developmental model.[1]	10. Make preliminary tests of maintainability and modify design as necessary.
Testing of service test model.[1] (Operational Suitability Test)	11. Make full-scale tests of maintainability and modify design as necessary.
Evaluation of prototype (preproduction) model.[1]	12. Evaluate maintainability of the system.
Engineering changes.	13. Correct deficiencies in maintainability of production equipment. 14. Review engineering changes for effect on maintainability.

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1. Models are defined in the Glossary of this report according to MIL-STD-243, Military Standard Types and Definitions of Communications - Electronics Equipment, 12 January 1954.

STEPS IN DESIGNING FOR MAINTAINABILITY

Step 1. Prepare Realistic Objectives for Maintainability

These objectives are guide lines for the team of designers developing a new system; as such, they are extremely important. If they are too stringent, valuable development time and funds will be wasted in trying to reach unattainable goals. If they are too lax, maintainability will suffer.

One important objective to be specified for maintainability is the maximum allowable turnaround time for line maintenance. This turnaround time directly affects the number of equipments that must be available in order for a specified number to be combat ready under various conditions. Turnaround time, therefore, should be a part of the operational requirements of the system, and maintainability design should aim to meet this requirement.

Turnaround time specified in this way provides a solid base upon which maintenance levels can be established, the equipment divided into units, and maintainability supports designed. Without this requirement stated, decisions on these problems are more arbitrary and the results less useful.

Principles for Preparing Objectives

Consider the way maintenance of the new system will best fit the Air Force plans for use of the system.

For example, if the equipment is to be based almost exclusively outside the continental United States, depot maintenance requirements should be minimized.

Constantly review the effects of one objective upon the others.

Practically all the objectives will be interrelated, so that stringent requirements for one phase of maintenance may raise problems for another. Thus, a requirement for rapid checkout at the line level may necessitate elaborate automatic test equipment which may be difficult to maintain.

This does not imply that such a requirement should not be made, but rather that the need for the rapid checkout first be verified.

Content of Objectives for Maintainability

Contractual provisions for development of maintainability supports.

These supports are listed on pages 8 and 9 in Section 2.

Limitations on final characteristics of the above supports.

For example, should go, no-go test equipment be developed so that untrained personnel can use it?

Schedules for phasing development of maintainability supports.

Phasing should be such that there is little chance that supports will be developed too early, resulting in wasted effort if the prime equipment is not acceptable; but there must be a high likelihood that these supports will be ready on time if the prime equipment is accepted and produced.

Step 2. Review Previous Systems

Careful analysis of earlier, similar systems is likely to assist the designer by making evident:

1. Maintainability features of the older systems that are applicable to the new system.

2. Defects in the maintainability of the older system that should be corrected on the new system.

Sources of information for this analysis are:

1. Unsatisfactory Reports, Failure Reports, and Tear-down Deficiency Reports.

   These are most likely to point out field changes that had to be made for maintenance. The need for such changes can be minimized by building the necessary features into the new system.

2. Interviews with maintenance personnel.

   These personnel are likely to recall some design features of the earlier systems that made maintenance particularly easy or particularly difficult. Inquiring separately about each maintenance task, such as preflight or alignment, will probably yield most information.

3. Designers of previous systems.

   Reports of unfruitful approaches to design for maintainability in the type of system in question, or suggestions for shortcuts in reaching certain decisions for this type of system should be obtained.

Step 3. Establish Adjustment Points and Self-Compensating Features

The purpose of this step is to minimize the adjustments that will be required in normal maintenance. The following substeps are suggested:

Check through the entire circuitry of breadboard and experimental models and list each component that is adjustable (other than by the operator's controls).

Replace as many of these components as practicable with components which do not require adjustment. Adjustments can be eliminated through the use of:

1. Components which will be less inclined to drift due to aging, shock, vibration, etc.

2. Positive feedback circuits to compensate automatically for drift.

3. Circuits with safety margins large enough to accept all of the shift in performance anticipated.

If none of the above steps is sufficient to prevent drift beyond tolerance limits, an adjustment point will probably be required.

Step 4. Determine Maintenance Levels

Decide the extent of maintenance to be performed at each maintenance level. The levels will probably be line (organizational), shop (field), depot, and periodic. The extent of maintenance recommended for each level should not be influenced by the way technicians will be assigned to the levels in the field. Whether a given man works in one level or two has little effect on what is the optimal division of functions between levels.

Line maintenance should be given primary consideration in designing for maintainability. This is the one level of maintenance which will necessarily be part of the maintenance picture, since this is the level of activity directed toward keeping the entire system in satisfactory operating condition. This is also the level at which the most serious maintenance problems seem to have occurred in the past. Maintenance at this level is usually under the greatest time stress. Delays in line maintenance are more likely to interfere with the functioning of operating organizations than delays at other levels. If there is a choice as to where added maintenance burdens should be placed, it will usually be less detrimental to total maintenance to place them on shop or depot than it will be to place them on the line.

Step 5. Divide Equipment into Units

Planning for division of the equipment into units should begin when schematics become available. Results of this planning should be recorded on wiring and/or layout diagrams.

Divide the equipment into replaceable units in the following steps:

1. Plan the division of equipment into line replaceable units.

2. Plan the division of line replaceable units into shop replaceable units.

3. Plan the division of equipment into depot replaceable units.

In each of the above steps make certain that the division of equipment into units is compatible with the following factors. Compromises will probably be required.

1. Over-all planning for maintenance as reflected in objectives for maintainability and descriptions of the various maintenance levels.

2. Recommendations for design of units presented in Section 4, pp. 41 to 52.

3. Good engineering practice. This involves such factors as grouping together equipment functions that will not interfere with each other, grouping together components which all use the same voltages.

4. Economic considerations. These will usually not conflict seriously with the above considerations. Where they do, remember that greater initial cost for good engineering or maintainability is likely to be regained in lower maintenance costs in addition to being a sound investment in combat readiness.

Consider the following in making these decisions:

For the line level the most important requirement is that the line technician, using the test equipment and tools assigned to him, will be able to isolate and replace malfunctioning units within the time allowed by the operational situation.

Particular attention should be given to the possibility of designing built-in test circuits for the use of the line technician. It is essential, of course, that such test circuits be highly reliable.

The considerations in dividing line replaceable units into shop replaceable units are similar to those in dividing the total equipment into line replaceable units.

Relatively more emphasis should be given, however, to the effect this division will have on requirements for logistics, training, tools, test equipment, and shop maintenance procedures.

Considerations in dividing the equipment into depot replaceable units are similar to those for line and shop except that economic considerations are paramount.

Whether a given assembly should be repaired and put back into service or discarded when it malfunctions depends on which alternative is more expensive. If the cost of facilities, equipment, and manpower for finding the trouble in assemblies and making the repair is greater than the cost of new replacement assemblies, the assemblies should be discarded when they malfunction. Conversely, if repair is relatively cheap, the assemblies should be repaired for re-use.

Step 6. Prepare Maintenance Procedures

Make a list of procedures to be prepared. Consider the maintenance levels one at a time.

For each level examine the probable needs for both preventive and corrective maintenance.

Make certain that procedures are listed for inspecting, checking, adjusting, replacing, repairing, trouble shooting, and servicing when appropriate.

Prepare procedures first for line level, then shop level, then depot level, then periodic maintenance. A form similar to the sample shown on page 142 in Section 5 will minimize omissions from any procedure.

Constantly review the effect of the procedures on the requirements for other maintainability supports; keep requirements reasonable.

Items to consider include:

1. Test points built into the equipment.
2. Test equipment, either standard or special.
3. Controls and indicators other than those already provided for the operator.
4. Tools, either standard or special.
5. Special information such as check readings which the technician who uses the procedure may require.

Review the procedures for conformance to recommendations in Section 5 and to operational requirements of the system.

It will probably be relatively easy to correct lack of conformance to recommendations in this guide. Conflict with operational requirements, however, may be more serious. If any procedure conflicts with the operational requirements (e.g., line trouble shooting cannot be done within the time allowed) the procedure should be revised. Changing the division of equipment into units or even redistribution of tasks among the various maintenance levels may also be required. In the event that all reasonable efforts at bringing the procedures into conformity with operational requirements fail, request a change in the operational requirements.

Step 7. Determine Requirements for Maintainability Supports

Go through each procedure step by step, and write down for each step the requirements for maintainability supports. Requirements will be adequately stated if each standard job support is listed and nonstandard items are described in detail for each of the following items for each maintenance level.

1. Prime Equipment Characteristics
   a. Special controls
   b. Special indicators
   c. Test points
   d. Special connections
   e. Special constructional configurations
   f. Special installation features
2. Test Equipment Characteristics
   a. Standard
   b. Special
3. Bench Mock-ups
4. Tools
   a. Standard
   b. Special
5. Information needed to perform the procedures

   (Readings and tolerances that will be needed by the technician)
6. Installation characteristics

Collate the requirements from various maintenance levels and procedures to form a single list. This eliminates duplication in requirements for maintainability supports and results in a single set of non-overlapping requirements.[1]

Requirements for personnel, work and storage facilities, supply channels, overhaul facilities, and equipment modification should also be identified and described.

Suggestions for these items are not included in this guide.

Step 8. Review and Modify Design for Maintainability

Review for reasonableness the requirements for each maintainability support.

The following questions can be asked about each support to help decide about its reasonableness:

1. Can it be obtained or developed within the budget and time limits of the project?

2. Can it be supplied and be used for typical field conditions?

3. Will it be economical to train personnel to use this job support?

4. Do the advantages of the item outweigh the cost of developing, procuring, and maintaining it?

Similar questions can be asked concerning whole classes of maintainability supports, e.g., test equipment, tools, etc. They can also be asked concerning all maintainability supports taken as a whole. Requirements taken as a group may be excessive even though requirements for no single support may be excessive. Thus a review of total requirements as well as individual requirements should be made.

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1. Provisioning of support items should be in accordance with Document MCP 71-650, Ground Support Equipment and Spare Parts Therefor Provisioning Document for United States Air Force Contracts, 25 April 1955.

Modify design recommendations if any requirements for maintainability supports are not reasonable.

Keep in mind that procedures, design of equipment, and maintenance levels are interdependent. Modification of one may also require modification of the others. If certain requirements for maintainability supports cannot be made reasonable within existing operational requirements, it may be necessary either to revise the criteria of reasonableness (e.g., increase the budget for test equipment) or modify operational requirements (e.g., increase the time allowed for line trouble shooting).

This review and modification <u>must</u> be completed before engineering design reaches the point where changes cannot practicably be made.

Step 9. Translate Design for Maintainability into Actual Equipment and Maintenance Instructions

This step includes fabrication of actual items of prime equipment and its maintenance support equipment such as tools and test equipment. It also includes the writing of maintenance job instructions in form for use by maintenance technicians. It should be scheduled into the total developmental sequence so that maintenance support items become available at about the same time as the completed developmental model of the prime equipment.

Step 10. Make Preliminary Tests of Maintainability and Modify Design as Necessary

Preliminary testing of maintainability is accomplished as a part of engineering testing of the developmental model by:

> Using the procedures developed for use by Air Force technicians in the field.

Using all auxiliary equipments specified for use by Air Force technicians in the field.

Using as maintenance personnel Air Force technicians with training similar to that planned for those who will maintain th equipment in the field.

It is likely that it will be practical to meet these conditions in only a small part of engineering testing. It may even be necessary to set aside some portion of the test period specifically for this purpose. But it should be done.

Modify design to correct deficiencies discovered in maintainability.

Step 11. Make Full-Scale Tests of Maintainability and Modify Design as Necessary

Full-scale testing of maintainability is accomplished as a part of the Operational Suitability Test by closely simulating maintenance field conditions during the test.

Particular attention should be given to adhering to the conditions suggested for preliminary testing of maintainability.

Participation of a specialist in maintainability in this testing is likely to be very helpful in discovering features which will cause maintenance difficulty in the field if not modified.

One limitation of this testing is the difficulty in making any but relatively minor changes in equipment because of the time and cost involved in redesign. This limitation becomes even more severe during later stages of development.

Step 12. Evaluate Maintainability of the System

During modification of the service test model into a prototype (preproduction) model, make a final reappraisal of the total design for maintainability. Modify the design to eliminate weaknesses.

Step 13. Correct Deficiencies in the Maintainability of Production Equipment

If maintainability testing and evaluation has been adequate, few unsatisfactory maintainability features should remain in early production equipment. Maintenance personnel should be alerted, however, to look for and report on Unsatisfactory Reports any undesirable maintainability features that do remain. The cost and time delay required to make the indicated changes should be weighed against the cost and delays in maintenance likely to result from not making the change.

Step 14. Review Engineering Changes for Effect on Maintainability

Once a piece of equipment goes into operational use, it is modified on the basis of Unsatisfactory Reports, Failure Reports, and Tear-Down Deficiency Reports submitted by field personnel. Each engineering change proposal suggesting such a modification should include a statement of exactly how the modification will affect maintenance at each level. This means that directions for field modification should include instructions for changing standing procedures for use on the modified equipment. In general, it is better from the maintenance standpoint, to make modifications in blocks so that maintenance personnel can keep track of them more easily.

section 4

Recommended Characteristics for Maintainable Equipment

OVERVIEW

This section contains concrete suggestions for design features to be included in all systems where feasible. The first nine subsections deal with the prime equipment. The next one deals with installation of the prime equipment. The last three subsections deal with auxiliary equipment needed for maintenance.

Suggestions for scheduling the recommendations of this section into the developmental cycle are, in general, not included in this section. The Design Schedule for Maintainability in Section 3 provides specific guides for scheduling design for maintainability into the technical development of the system.

In contrast to other sections in this guide, this section is not designed to be read from start to finish. Rather, it is an encyclopedia of design features to be referred to when specific problems of hardware design are being considered.

Equipment Units

Purpose of Unitizing Equipment

The primary purposes of unitizing equipment from a maintenance standpoint are to:

Permit division of maintenance responsibility, particularly trouble shooting, among various maintenance levels. This permits rapid corrective maintenance at the line level with additional maintenance at other levels.

Provide easy access to malfunctioning components. It may, for example, be much easier to remove an assembly from a major component and then work on a part than it would be to work on the same part when mounted directly within the major component.

Effect of Maintenance Levels and Procedures on Design of Units

There is interaction among unit design, maintenance levels, and maintenance procedures. For example, if maintenance procedures specify that a particular major component should be brought to the shop if it contains <u>any</u> malfunction, there is little point in designing the component so assemblies contained within it are removable on the line.

The Design Schedule for Maintainability in the previous section suggests some of the considerations for integrating the design of units with procedures for each maintenance level. Only through such integrated design can unitization be maximally effective for maintenance. For example, the design of two similar major components should probably differ appreciably if procedures specify that one is line replaceable and the other is not replaced at the line level but contains a number of line replaceable assemblies.

Functional Interrelationships of Units

Minimize the number of inputs to and outputs from each unit at each maintenance level. This can be done by grouping circuits so that minimum crisscrossing of signals between units is required.

No unit should have more than about 30 volts applied to it (for heater or standby) when the main power switch for the equipment is turned "off."

Units should not be "married" to each other. It should be possible to check and adjust each unit separately, and then connect the units together into a total functioning system with little or no additional adjustment required.

Provide overload indicators on each major component even if it is sometimes desirable to keep overloaded circuits in operation.

Interchangeability of Units

Regularly stocked parts should be used whenever feasible.

As many assemblies, subassemblies, and parts should be interchangeable within and between equipments as feasible. Interchangeability of components reduces supply problems.

The number of different sizes and types of screws and quick connectors used on an equipment should be kept to a minimum.

Labeling and/or Coding of Units

All units and parts should be labeled with full identifying information, including if possible, the Air Force stock number.

The outside covering of manufactured parts such as resistors, condensers, and tubes should be stamped with relevant information concerning electrical characteristics of the part, when feasible. Direct presentation of this information makes interpretation easier than color coding.

Each terminal should be labeled with the same code symbol as the wire to be attached to it.

Labels should be etched or embossed into the component or chassis rather than merely painted or stamped on the surface.

If surface labels must be used, decals or stamped labels are preferable to stenciled labels because they are usually easier to read.

Labels should not be hidden by units and parts. For example, labels stamped on the chassis should not be placed under the parts which they identify.

MOUNTING BOLTS AND FASTENERS

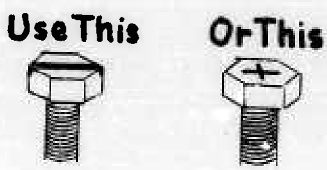
Fasteners for assemblies and subassemblies should fasten or unfasten in a maximum of one complete turn.

If bolts are needed, the number of turns required to tighten or loosen them should be minimized.

Hand-operated fasteners are best; those requiring standard hand tools are acceptable; those requiring nonstandard tools should be avoided.

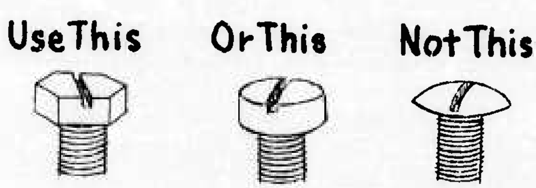
Use combination-head mounting bolts with a deep internal slot arrangement and hex head.

This type of screw can be operated with a standard screwdriver, but a wrench can be used on jammed bolts.

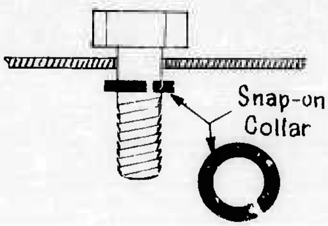


Always provide an external-grip head on bolts requiring high torques.

This will reduce the need to drill out bolts with damaged slots. Even round Fillister heads permit a grip with a vise pliers if the slot is damaged.



Make mounting bolts semipermanently captive. Snap-on collars are good for this purpose. They permit easy replacement of damaged bolts.



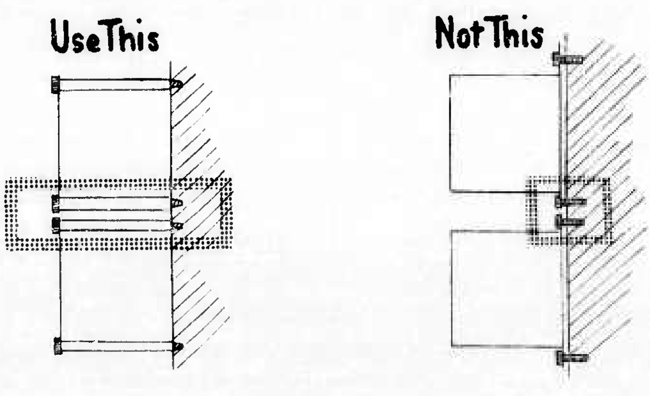
Mounting bolts and fasteners should be clearly labeled as such.

An "M" embossed on the top of the head would be good if the practice could be widely used.

Use a rust and damage resistant material for mounting bolts and fasteners.

Mounting screws should be interchangeable whenever feasible. Use as few different sizes as practicable.

Place heads of mounting bolts and fasteners on a surface adjacent to the technician's work space.



MOUNTING AND ASSEMBLING PROVISIONS

Field replaceable assemblies and subassemblies should be plug-in rather than solder connected whenever feasible. This is true of large assemblies and small subassemblies such as electrolytic condensers, relays, and miniaturized throwaway circuits.

No more than four screws should be used for mounting a major unit in an installation unless stress considerations require more.

Assemblies and units should be replaceable with nothing more than common hand tools.

Units which must frequently be pulled out of their normal installed position for checking should be mounted on roll-out racks, slides, or hinges.

Always provide guide pins on units and subassemblies for alignment during mounting.

Always provide limit stops on roll-out racks and drawers to prevent their being dropped.

It should be easy to override these limit stops for replacement of racks and drawers.

Mount units and assemblies so that replacing one unit does not require removal of other units for access.

Covers or shields through which mounting screws must pass for attachment to the basic chassis of the unit should have large enough holes for passage of the screw without perfect alignment.

LOCATION OF COMPONENTS WITHIN UNITS

Parts should be mounted in an orderly array on a "two-dimensional" surface, and not "stacked" one on another.

Orderly layout is helped by mounting parts to one side of a board and wiring (including printed or soldered circuits) to the other side, with electrical contacts inserted through the board.

Locate parts so that large manufactured parts such as indicator and magnetron tubes which are difficult to remove do not prevent access to them.

Components should be placed so that:

1. There is sufficient space to use test probes, soldering irons, and other required tools without difficulty.
2. Tubes can be replaced without removing assemblies and subassemblies.
3. Resistors, capacitors, wiring, etc. do not interfere with tube replacement.
4. Structural members of units do not prevent access to components.
5. All throwaway assemblies or parts are accessible without removal of other components.

If line maintenance procedures require tube replacement it should not be necessary to remove units from their installation to make such replacements.

Locate all fuses so that they can be seen and replaced without removing any other parts or subassemblies. Tools should not be required for replacing fuses.

Delicate components should be located where they will not be damaged while the unit is being worked on.

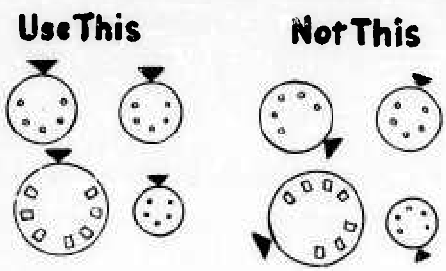
> For example, resistor boards should not be in a position where the technician is likely to strike them with his hand or arm when making adjustments.

Internal controls such as switches and adjustment screws should not be located close to dangerous voltages.

If screwdriver adjustments must be made blind, the screws should be mounted with their shafts vertical so the screwdriver will not fall out of the slot.

Components which retain heat or electrical potential after the equipment is turned off should not be located where technicians are likely to touch them while changing commonly malfunctioning parts such as tubes.

Orient all miniature tube sockets with the gap facing in one direction to help in replacing tubes.

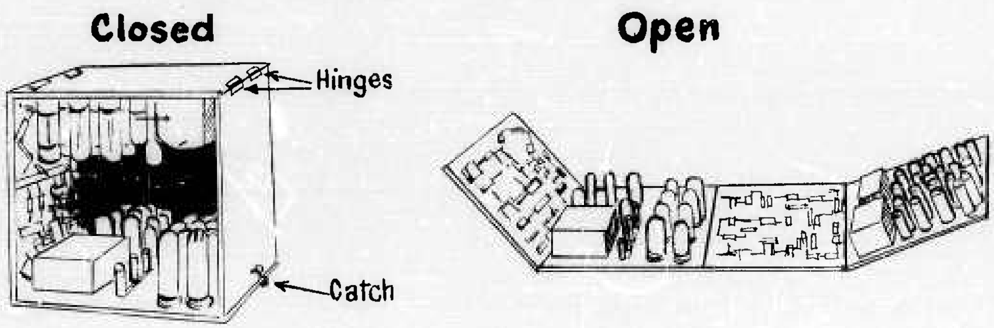


STRUCTURE OF UNITS AND ASSEMBLIES

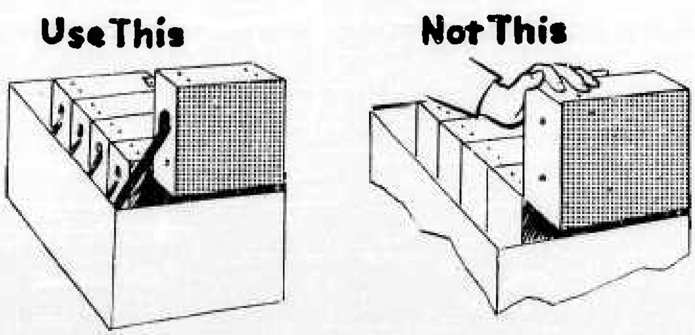
Only interconnecting wiring and structural members should be permanently attached to the unit chassis. All parts (resistors, condensers, tube sockets, etc.) should be mounted on subassemblies, or much of the value of unitization is lost.

Provide fold-out construction of subassemblies whenever feasible.

Position parts and wiring to prevent damage to them from opening and closing the assembly.



Provide a brace or other provision to hold hinged assemblies in the "out" position while they are being worked on.



Provide rests or stands on which units can be set to prevent damage to delicate parts. The rests or stands should be a part of the basic chassis if feasible.

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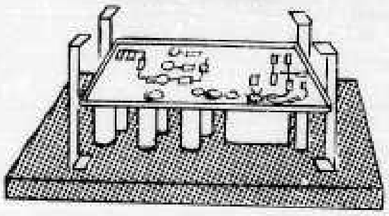

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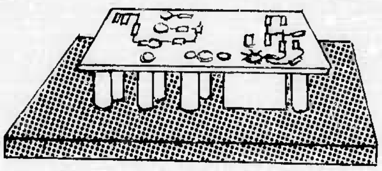

Make stress members of units strong enough to withstand the usual blows they receive in handling and transportation for maintenance.

Units should be small and light enough for one man to carry and handle, whenever this arrangement is feasible technically. See "Weight Lifting Capacity" of personnel on page 12.

Units should be designed so individuals handling them are protected from sharp edges, points, heat, and electrical charges.

Irregular extensions such as bolts, cables, wave guides, and hoses should be easily removable before the unit is handled. Such protrusions are easily damaged and make handling of the unit awkward.

Units weighing more than ten pounds should have convenient handles to assist in removal, replacement, or carrying.

Provide handles even on small light units which would otherwise be difficult to grasp, remove, or hold without using delicate components as grips.

COLOR CODING[1]

The meaning of colors should be explicitly stated in printed job instructions and/or on a panel of the equipment having the color coding.

The meaning of a particular color should be consistent throughout a prime equipment and its maintenance supports. It should also be consistent for different equipments, insofar as this is possible.

Only three colors of coded signal lights (e.g., for panel lights on testers) are recommended if color defective technicians will use them. They are aviation red, aviation green, and aviation blue as defined by Military Specification MIL-C-25050 (ASG), 29 October 1954, Colors, Aeronautical Lights and Lighting Equipment, General Requirements for. Don't use white or yellow with the three recommended colors because color defective technicians may confuse red with yellow and green with white.

Surfaces painted with the colors listed below will be clearly distinguishable from each other.[2]

Red.....1110	Blue.....10B 7/6	White...1755
Orange..1210	Purple...2715	Black...1770
Yellow..1310	Gray.....1625	Buff....1745

Black, white, yellow, and blue are easily distinguishable by most persons, even those with defective color vision (who comprise about six percent of the male population).

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1. These suggestions are taken primarily from the following two sources:
   Baker, C. A. and Grether, W. F. (Reference 1)
   Spector, P., Swain, A. D., and Meister, D. (Reference 7)

2. The numbers refer to colors for ready mixed paints (Reference 9) with the exception of blue 10B 7/6 which follows Munsell, A. H. (Reference 6).

If more than four colors are needed, the other colors listed above are the best even for persons with defective color vision.

No more than the nine different colors suggested above should be used on any one equipment. This will usually be more than enough to differentiate parts of the equipment. However, if more are needed, check patterns of contrasting colors should be used rather than using solid intermediate colors. Some combinations of contrasting colors are suggested below:

White-------------Black
White-------------Red
Bright yellow-----Black
Bright yellow-----Blue

OTHER CHARACTERISTICS FOR UNITS

Treat metal surfaces as necessary to inhibit corrosion.

Maintenance is usually easier when a whole unit rather than a circuit or portion of a circuit running through a unit is pressurized.

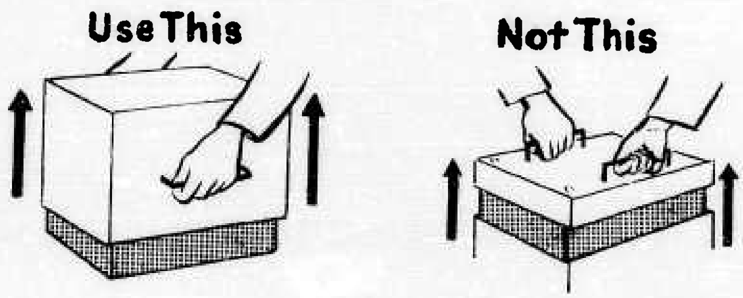
Units containing mechanical components such as gear trains should have provision for lubrication without disassembly or should not require lubrication (be sealed in a lubricant).

Colors should be permanent. They should not wear off or fade.

Covers and Cases for Equipment Units

STRUCTURE

Design so that cases can be lifted off units rather than units lifted out of cases. This is particularly true of heavy units.



Make cases enough larger than the units they cover so that wires and other components are not likely to be damaged when the cases are put on or taken off.

Guides and tracks help to prevent cases from cocking to one side and causing damage.

When the edges of a case must be slid over rubber stripping or other sealing material, the sealing material should be adhered tightly enough so that it does not buckle or tear, damaging the seal or jamming the case.

Use hinged covers to reduce the number of fasteners needed. Nonpressurized units may need only one fastener with a hinged cover. Keep in mind that a hinged cover requires a space equal to the size of the cover in which to open, which may be a disadvantage.

The method of opening a cover should be obvious. If it is not obvious from the construction of the cover itself, an instruction plate should be permanently attached to the outside of the cover.

It should be obvious when a cover is in place but not secured. Otherwise, the unit may be picked up by its loose cover and dropped.

Covers and cases should have rounded corners and edges for safety.

FASTENERS FOR COVERS

Make maximum use of tongue-and-slot catches to minimize the number of fasteners required.

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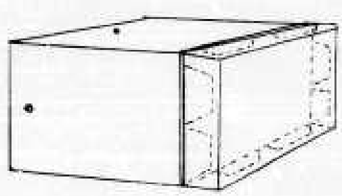

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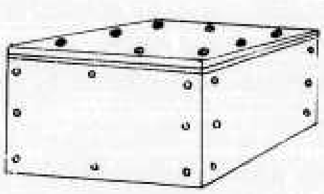


Use as few fasteners as possible to maintain required strength and bonding.

> In most cases one fastener at each corner of a rectangular cover or three on a round cover will be adequate. In some cases one fastener at each end of a diagonal will be enough.

Use the same size and type of fasteners for all covers and cases on a given equipment where practicable.

> Exception: If a system has one or two pressurized units requiring large fine threaded screws to hold the pressure, do not use that type of screw on other units having only dust covers. Use quick-acting fasteners on the dust covers.

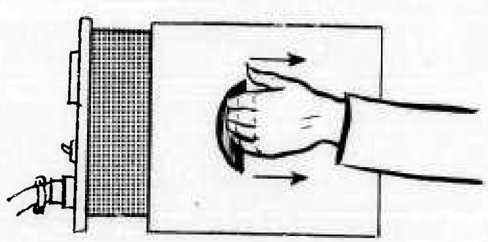
Screws with different threads should be different sizes. Otherwise they may be forced into the wrong holes and stripped.

See also "Mounting Bolts and Fasteners," page 44.

HANDLES

Provide handles on covers to facilitate removal of the cover and carrying of the unit.

Use This



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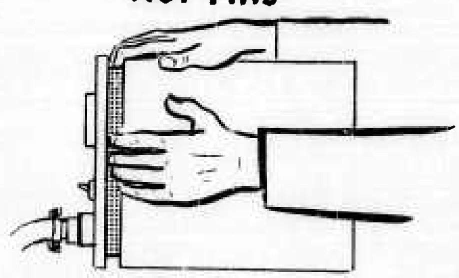
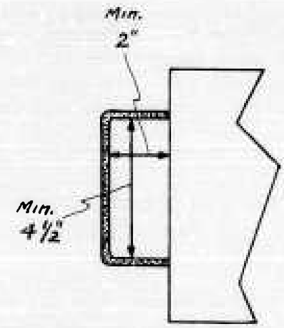


Locate handles over the center of gravity of units so they do not tend to tip when being lifted or carried.

Handles which technicians must grip firmly should be at least four and one-half inches in height and two inches in depth. Handles which are smaller will cause technicians' hands to be squeezed, resulting in discomfort and inability to exert full force.



OTHER CHARACTERISTICS FOR COVERS

Covers and cases should have their own stock numbers in the event they have to be replaced.

Ventilation holes in covers should be small enough so test probes or other conductors cannot be inserted inadvertently and touch high voltage sources.

Interconnecting Wires and Cables

WIRE AND CABLE CONSTRUCTION

Cables should be long enough so that:

Each functioning unit can be checked in a convenient place. (Extension cables should be provided where this is not feasible.)

Units in drawers and slide-out racks can be pulled out without breaking electrical connections, and connectors can be reached easily for replacement or repair.

Units which are difficult to connect when mounted can be moved to a more convenient position for connecting and disconnecting their cables.

Length of cables should be the same for each installation of a given equipment if circuit functioning may be significantly affected by differences in cable length.

Even if component adjustment can compensate for differences in cable length, the use of different cable lengths in different installations may make bench adjustments inaccurate for a given installation. An adjustment which is correct for the bench mock-up may throw an installed equipment out of tolerance if it has different length cables.

Cable harnesses should be designed so that they can be fabricated in a shop or factory and installed as a unit.

Cables should be "fanned out" in junction boxes for checking if other test points that will give the same information are not provided. This arrangement requires that each check point be accessible for test probes and be clearly labeled. It also requires that maintenance instructions and diagrams indicate the location (physical and functional) and use of these points.

CABLE ROUTING

Route cables so that:

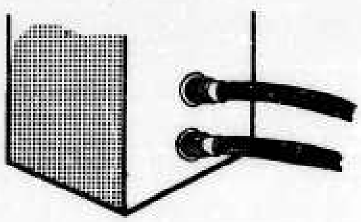
They cannot be pinched by doors, lids, etc.

They are very unlikely to be walked on or used for handholds.

They are accessible to the technician; not under floorboards or behind panels or components that are difficult to remove. This is particularly important for waveguides and high frequency or insulated high voltage cables.

They need not be bent and unbent sharply when they are connected or disconnected.

Use This



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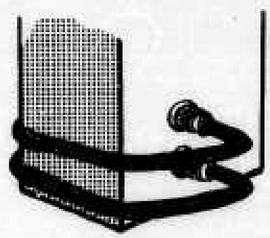


Provide guards or other protection for easily damaged conductors such as waveguides, high frequency cables, or insulated high voltage cables.

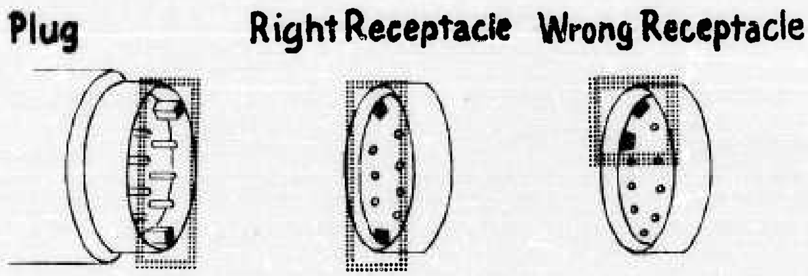
CONNECTORS FOR CABLES AND WIRES

Identification

Design plugs so that it is impossible to insert any plug in the wrong receptacle. Either of the following methods is adequate:

Make nearby plugs different sizes.

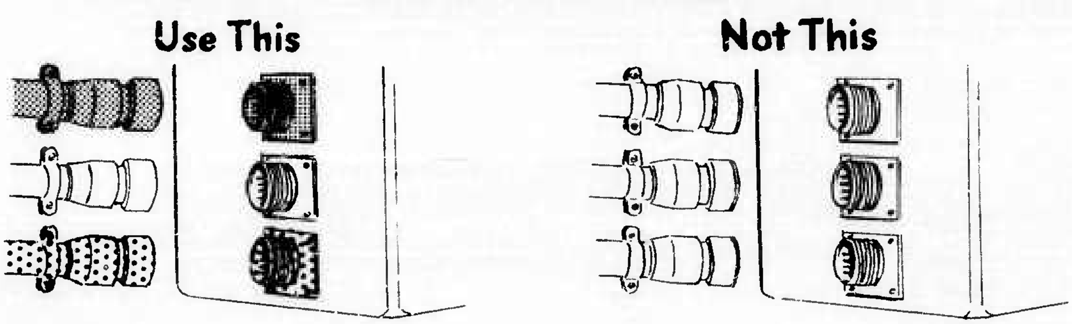
Use different keys or aligning pins on nearby plugs.



Plugs and receptacles should have painted stripes, arrows, or other indications to show proper position of keys or aligning pins for proper insertion position.

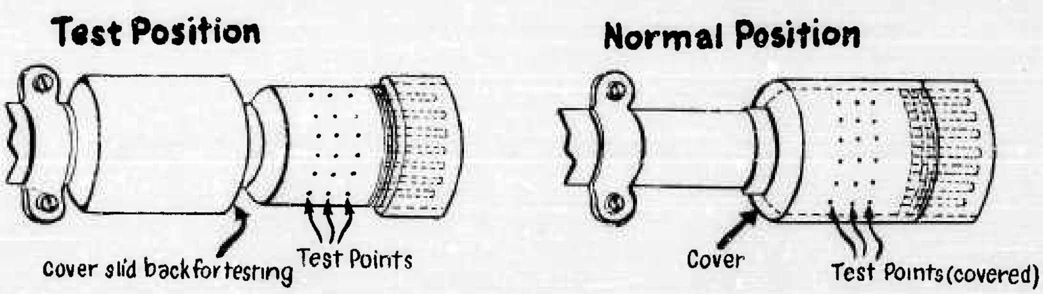
Each pin on each plug should be clearly identified.

Code each plug to the receptacle to which it is to be attached. Color coding may be a convenient means of coding.

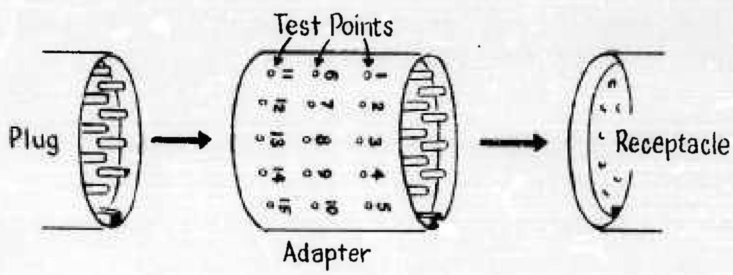


Test Points on Connectors

Plugs should provide access to each replaceable unit input and output for which a special test point has not been provided. If dust or moisture is a problem, plugs with test points may be constructed with a built-in cover.



If it is not feasible to provide test points in plugs, adapters with test points should be provided for insertion between plug and receptacle.



Provisions for Connecting and Disconnecting Cables

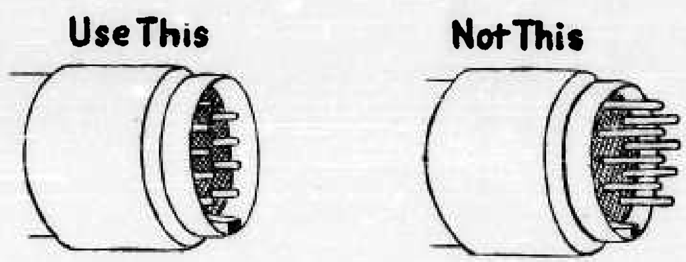
Plugs requiring no more than one turn, or other quick disconnect plugs, are preferred over plugs with fine screw threads requiring many turns.

Use plugs with a self-locking safety catch whenever feasible, rather than plugs which must be safety wired.

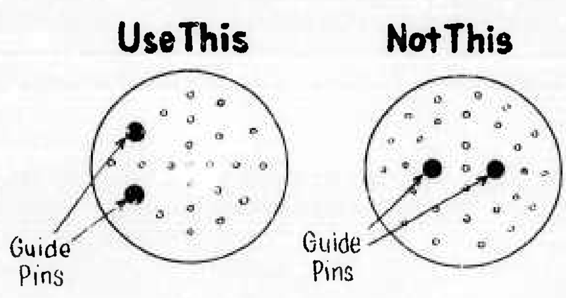
Plugs which need safety wiring should have provision (e.g., holes or hooks) for such wiring. There have been cases where such provisions have been omitted.

It is easier to connect and disconnect units having a few cables with many pronged plugs than units having many cables with fewer prongs. It takes about the same amount of time to connect a plug with many prongs as it does to connect a plug with a few prongs.

Aligning pins or keys should extend beyond electrical pins. This protects the electrical pins from damage through poor alignment with the receptacle or twisting of the plug when partially inserted.



Avoid symmetrical arrangements of aligning pins or keys. Such arrangements permit a plug to be inserted 180 degrees from the correct position.



Design of connectors should prevent electrical contacts from being shorted by external objects.

Plugs which must be removed for preflight checking should be most accessible to the line technician. Preflight procedures and equipment design, however, should make removal of plugs unnecessary for preflight checks insofar as possible.

Connectors should be located far enough apart that they can be grasped firmly for connecting and disconnecting. The space required will depend on the size of the plugs.

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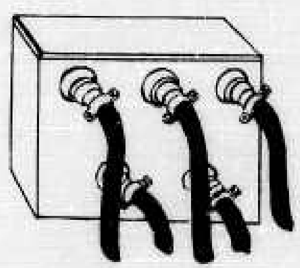

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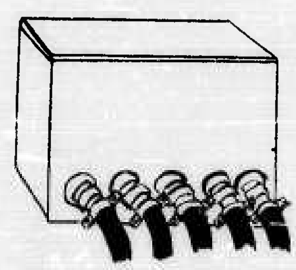
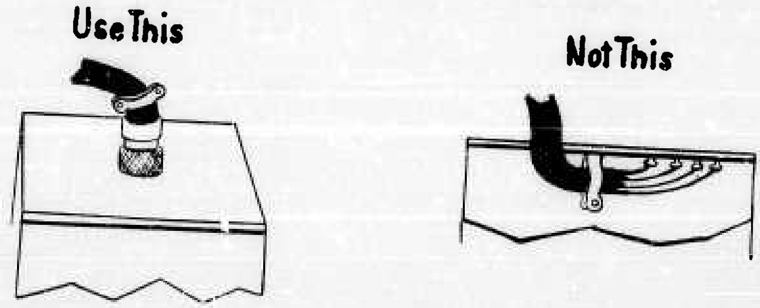


When a mechanical portion of a total weapon system (e.g., the tail section of an aircraft) is removable for maintenance, cabling connecting the removable portion from the rest of the system should have a plug and receptacle which will disconnect before the cabling breaks.

> Particularly if nonelectronics maintenance personnel do the removing, plugs may not be disconnected until considerable strain has been placed on the cabling. A jerk-open plug will part before damange is done to the cabling. A screw plug probably will not.

Whenever practicable design the system so that receptacles are "hot" and plugs are "cold" when disconnected.

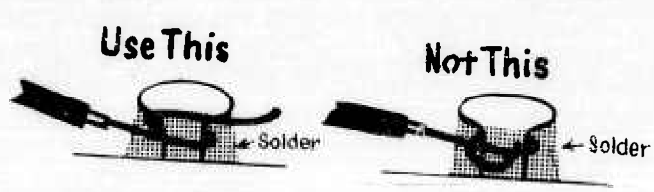
Provide plugs and receptacles for connecting cables to equipment units. When cables are "pigtailed" to units, the units are somewhat harder to replace; damaged cables are much more difficult to replace.



Wire Connections

Plug-in contacts are usually the easiest to connect and disconnect, screw terminals are of medium difficulty, and solder connections the most difficult. From the standpoint of easy maintenance, the more easily connected and disconnected types should be used whenever feasible.

The end of a wire soldered to a terminal should be left out of the solder to simplify removing it.



Leads to which wires are to be soldered should be far enough apart so work on one lead does not damage neighboring leads or other components.

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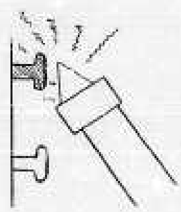

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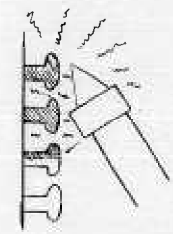

Terminals or other connections to which wires are to be soldered should be long enough so insulation and other surrounding materials are not burned by a hot soldering iron.

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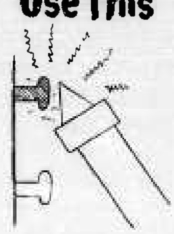

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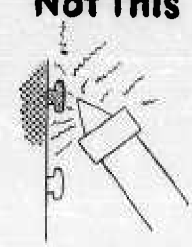
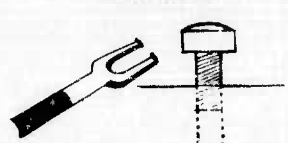


Use  lugs rather than  lugs whenever feasible.

Use This



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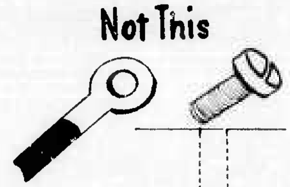


Accesses

Importance of Accesses

Adequate accesses are a necessary condition for effective maintenance. If proper accesses are not provided or are difficult to reach or use, large covers will have to be removed unnecessarily, fittings in hydraulic or air lines will have to be opened, and maintenance tasks will probably not be performed as specified.

When an Access is Needed

Provide an access whenever a frequent maintenance operation would otherwise require removing a case or covering, opening a fitting, or dismantling a component.

Procedure for Access Design

List the parts of equipment to be reached through each access and the operations to be performed on each part using that access. Then design the access to make those operations as simple as possible. Remember that accesses include not only entrance doors; but also inspection windows and lubrication, pneumatic, and hydraulic replenishing points.

LABELING AND/OR CODING

Each access should be labeled with a number, letter, or other symbol designation assigned only to that access so each one can be clearly named in job instructions.

Where tubes or plugs have to be inserted through small accesses, an external indication of the position for pin insertion should be provided, e.g., matching stripes or dots on tube or plug top and on the cabinet.

Label each access with the nomenclature for items accessible through it. For example: "CSM adjust," or "Dynamotor brush access," or "Antenna drive lubrication."

Each access should also be labeled with the nomenclature for auxiliary equipment to be used at it. For example:

Antenna drive lubrication
Grease Gun 7208,
Grease MIL-27-8694

Indicate under each access the recommended periods for accomplishing operations either in calendar time or operating time.

If it is not feasible to present any of this material on or near the access, it should be presented in job instructions and identified by the symbol designation labeled on the access.

TYPE OF OPENING FOR PHYSICAL ACCESS

Use a hinged door where physical access is required (instead of a cover plate held in place by screws or other fasteners).

If lack of available space for opening the access prevents use of a hinged opening, use a cover plate with captive quick-opening fasteners.

If a hinged access or quick-opening fasteners will not meet stress, pressurization or safety requirements, use the minimum number of the largest screws consistent with these requirements.

TYPE OF ACCESS FOR VISUAL INSPECTION ONLY

Most desirable

Use an opening with no cover unless this is likely to degrade system performance.

Use a plastic window if dirt, moisture, or other foreign materials are a problem.

Use a break-resistant glass window if physical wear or contact with solvents will cause optical deterioration.

Use a quick-opening metal cover if glass will not meet stress or other requirements.

Least desirable

TYPES OF ACCESS FOR TOOLS, TEST LEADS AND SERVICE EQUIPMENT

Most desirable	Use an opening with no cover unless this is likely to degrade system performance.
↓	Use a spring-loaded sliding cap if dirt, moisture, or other foreign materials are a problem.
Least desirable	Use a quick-opening cover plate if a cap will not meet stress requirements.

ACCESS AND SAFETY

Provide edges of accesses with internal fillets, or rubber, fibre, or plastic protection if they might otherwise injure the technician's hands or arms.

Provide safety interlocks on accesses which lead to equipment with high voltages. If the technician may need to work on the equipment with the circuit on, provide a cheater switch that automatically resets when the access is closed.

Provide screwdriver guides to adjustment points which must be operated near high voltages.

SHAPE OF ACCESS

Make access doors whatever shape is necessary to permit passage of components and implements which must pass through. Access openings need not necessarily be a regular shape like square or round. If, for example, structural members in units prevent an access of regular shape being made large enough for the function it must serve, make the access whatever shape is needed.

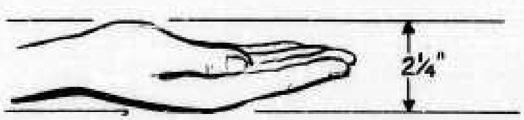
LOCATION OF ACCESSES

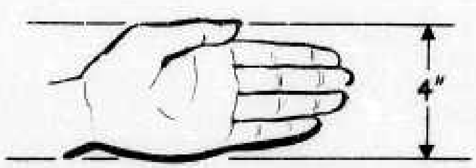
Location of accesses for line maintenance should be dictated by the way in which units are installed. Determine which faces of the unit will be accessible in the normal installation and place accesses on one of these faces. All accesses, displays, controls, cables, etc., should be put on the same face of a unit whenever possible. It is usually easier to keep only one face readily accessible in an installation than it is to keep more than one readily accessible.

Place access openings to permit maximum convenience in performing job procedures. Determine what the technician will have to do through a given access and place the access to accommodate that operation.

SIZE OF ACCESSES FOR ONE-HAND TASKS[1]

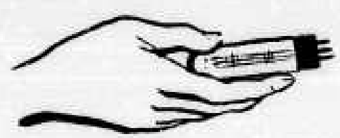
Inserting empty hand held flat. 2 1/4" x 4"



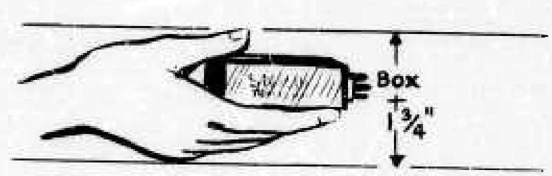


1. The suggestions for minimum access sizes in this section are based mainly upon very informal measurements taken by project staff members on one another. Some are based upon systematic data collected on a small sample of subjects performing certain tasks (this study to be reported separately), and others are extrapolated from carefully collected and analyzed anthropometric data as reported in Hertzberg, H. T. E., Daniels, G. S., and Churchill, E. (Reference 3). All dimensions presented are offered only as useful approximations. Where the extrapolation from our measurements or from the anthropometric data may be somewhat tenuous, an attempt was made to err on the safe side by adding a margin of safety judged by the authors to be adequate. These dimensions will provide adequate space for about 95% of technicians.

Smallest square hole through which empty hand can be inserted.	3 1/2" x 3 1/2"
Inserting a miniature vacuum tube, held with the thumb and first two fingers, up to the center knuckle of the middle finger.	2" x 2"



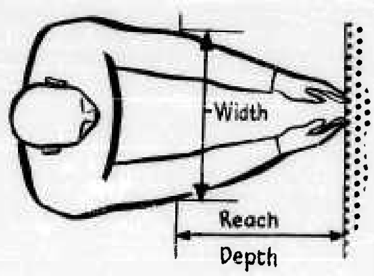
Inserting a large vacuum tube (CRC 1625; base dia. 1 3/8", height 4 1/2" excluding pins and grid cap).	4" x 4"
Using an eight-inch screwdriver with a one-inch diameter handle.	3 3/4" x 3 3/4"
Inserting and tightening an AN plug (14 pin connector; outside dia. 1 7/8").	4" x 4"
Inserting a box (or electronic assembly) held in one hand.	Width of box +1 3/4"



SIZE OF ACCESSES FOR TWO-HAND TASKS[1]

If an object is heavy for the position in which it has to be handled or if an object is held while a tool is operated (e.g., screw and screwdriver) the technician may need to insert two hands and two arms through the access. Make the access door big enough to allow this.

Inserting a box (or electronic assembly), grasped by handles on front, into an aperture (box was 8" x 8" x 8", weighed 24 lbs.).	1/2" clearance on each side of box
Reaching through access with both hands to a depth of 6 to 25 inches.	Width = 3/4 depth of reach Height = 4 inches



1. See footnote on page 69.

Reaching in full arms length (to shoulders), straight ahead, with both arms.

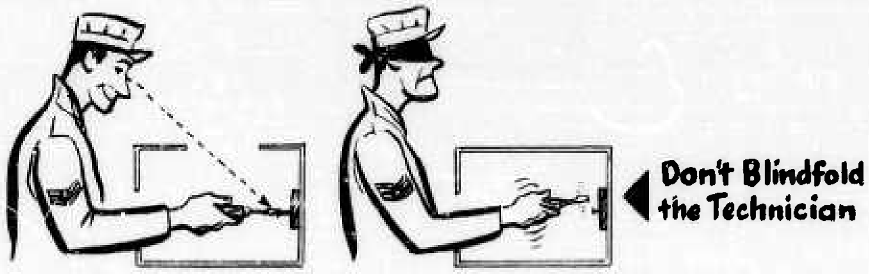
Width of access: 19 1/2"

Determine what the technician will have to see by studying the operations he will have to perform through the access before deciding on the access size.

For some operations it may be better to place the access to the side instead of directly over the operation.

If the technician must be able to see what he is doing inside the equipment, the access must be large enough for the technician's hand(s) or arm(s) and still leave an adequate view of what he is doing.

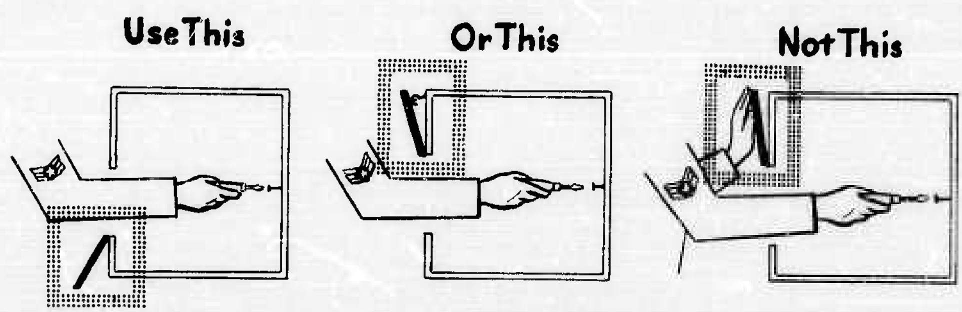
Sometimes one access door and one window may be called for.



MEANS OF OPENING AND CLOSING ACCESSES

Use a few large screws instead of many small screws in access covers which must also serve as stress members, insofar as this is compatible with stress requirements.

On hinged access doors place the hinge on the bottom or provide a prop so that the door will stay open without being held if unfastened in a normal installation.



See also "Fasteners for Covers," page 54.

MEANS OF ATTACHING AUXILIARY EQUIPMENT

Connectors for auxiliary equipment should require no tools for their operation. If tools must be used, standard hand tools should suffice to operate connectors.

Connectors for auxiliary equipment should operate in a fraction of a turn or with quick snap action.

Test Points

Importance of Test Points

Strategically placed test points are indispensable to effective design for maintainability. They provide the technician his only practical means of looking into the functioning of a system, except for the information obtainable from operator displays.

Use of Test Points

Test points make signals available to the technician for checking, adjusting, or trouble shooting. In order to be of maximum benefit for any of these functions, test points must be in the proper functional location (tie into the circuit where the technician needs to sample signals) and physical location (be placed where the technician can reach them easily). They should be labeled for easy identification and designed for easy attachment of test equipment.

The most important use of test points is in trouble shooting. The majority of the following recommendations pertain to this use.

Information Available at Test Points

Test points should make available the signals which carry information through the system as well as the various power-supply voltages used in the equipment. Out-of-tolerance signals usually cause the final output of the system to be unsatisfactory. If the final system output is not satisfactory, it should be possible to determine what portion of the system is malfunctioning by tracing signals and determining at what point one of them becomes out of tolerance. This process of trouble shooting is virtually impossible if signals are not brought to test points.

Interdependence of Maintenance Procedures and Test Point Location

Maintenance procedures and specifications for test points should be prepared concurrently so that necessary compromises can be made between technical limitations and optimum procedures design. Physical location of the test points must also be considered in this development, since the feasibility of a certain functional location may be determined by the physical location which can be provided. For example, it may be feasible to provide a test point for a given point in the circuit only if the lead to that test point is no more than an inch or two in length so the signal is not lost in transmission. If the physical location of a test point meeting these requirements were such that the technician could not reach it, a substitute procedure and functional location for the test point would have to be found so that the physical location of the test point would be satisfactory.

FUNCTIONAL LOCATION OF TEST POINTS

The functional location of test points should be fixed by determining from the maintenance procedures what signals must be available to the technician and at what points they must be available. Test points are merely job supports for procedures - they make available those signals which the procedures dictate the technician must have in order to maintain the system. This means that test points should not be randomly placed throughout the system wherever it is technically convenient, but that they must be planned into the system. For line maintenance, for example, a test point should be available for each input and output of each line replaceable unit.

PHYSICAL LOCATION OF TEST POINTS

The physical location of test points determines their ease of use and the likelihood that the procedures for which they were included will be followed. In this way the physical location of test points has a marked effect on the quality of maintenance.

Generally speaking, test points should be concentrated in one place. Practical limitations do not always permit this arrangement. Already developed equipment may have to be used or the nature of a signal may be such that it does not travel well without being altered in the process of transmission. The designer should keep in mind, however, that it is not mandatory that the technician be able to sample the true signal as it appears in a circuit. All that he may need is an indication which reflects an out-of-tolerance condition of the true signal when one exists. If these indications are checked and recorded during engineering tests, they should be adequate for field use. This consideration is particulary pertinent in those cases where the wave shape of the signal is critical and will tend to change in transmission to a test point.

Test points should be accessible in the particular installation. Internal test points should be clustered around the portion of the units which will be most accessible when installed. For example, the side of a unit containing the operator's controls and displays is likely to be more accessible for maintenance than the side of the unit opposite the controls.

> <u>In airborne equipment</u> the test panel should be just under the skin of the aircraft, accessible through an access door, or should be located so that it can be reached conveniently from the crew's compartment.
>
> <u>In ground equipment</u> the test panel should be about four to five and one-half feet above the surface on which the technician will stand while using the panel.

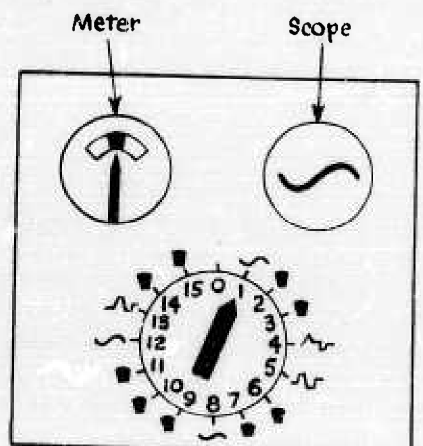
GROUPING OF TEST POINTS

Suggested groupings of test points for a particular type of technician (e.g., fire control--line level) are given below, with the one judged most desirable presented first, the next best second, and so on. These arrangements are merely samples and are not intended to exhaust all possible ways in which test points can be arranged. They are intended to help the designer evaluate the adequacy of his own plans for test point arrangement.

BEST GROUPING:

This arrangment, built in as part of the installation, seems best. It assumes that both voltages and wave shapes must be checked for trouble shooting or system checkout.

> Note: Meter and scope have fixed preset circuits so that the meter always reads center scale and the scope needs no adjustment. In-tolerance reading for each switch position is indicated on the switch face.



Selector Switch

FIRST ALTERNATIVE GROUPING:

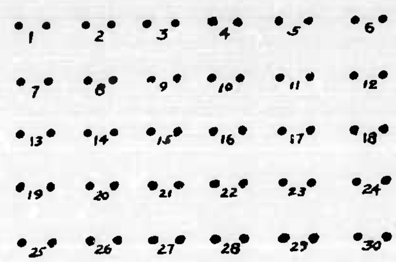
If the above arrangement is not feasible because of space and/or weight limitations, a portable test box similar to the built-in device suggested above should be used. It should have a single multi-prong contact for attachment to a central test panel.

If too many test points are needed for a single switch in either of the above arrangements, a multiple switch arrangement can be used.

SECOND ALTERNATIVE GROUPING:

If for some reason the auxiliary equipment as illustrated by the first alternative cannot be provided, at least a test panel should be added to the equipment. Standard test equipment can be used by the technician in conjunction with this panel. This arrangement provides, in effect, a miniature block diagram of the system, with each block representing a line replaceable unit.

Test Panel

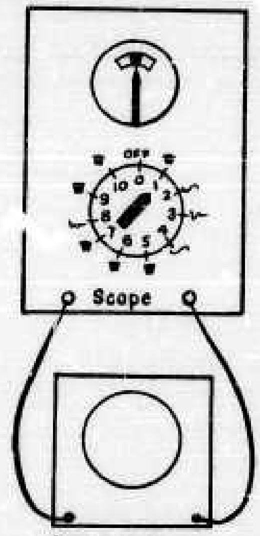


In this arrangement a test point is provided for the input and output of each line replaceable unit to permit isolation of malfunctions to those units. Various overlays can be provided to place over the test panel. These overlays should be coordinated with maintenance procedures and be designed so as to direct the technician to those test points which he should check and the order in which he should check them. Exact in-tolerance signals can be shown on the various overlays for each test point, even though the signals change at various steps in the checking or trouble-shooting procedures.

Test points should be coded on the panel for identification in the event that overlays are lost. A code key should be included in job instructions.

THIRD ALTERNATIVE GROUPING:

If a central test panel for the system is not feasible, ideally the test panel illustrated above under "Best" should be used on each major component. Since this may not be practicable in many cases--because scopes are large, heavy, and expensive--the following arrangement is suggested.



Standard Scope

Mount a center-reading meter on each major component for those signals which can be checked by meter. Provide a set of test jacks on each major component which will serve as an outlet for signals requiring a scope when they are selected by the switch. The selector switch should be similar to those suggested above.

If this arrangement cannot be used, the panel of test jacks as described in the second alternative should be used on each major component.

FOURTH ALTERNATIVE GROUPING:

If none of the above arrangements is feasible, test points for line maintenance should still be provided for inputs and outputs on each line replaceable unit. This arrangement is by far the least desirable. Particular attention should be given to making these test points accessible, if this alternative must be used.

All test points should be placed or guarded so that the technician is physically prevented from contacting high voltage while using them.

LABELING OF TEST POINTS

Each test point should be labeled with a symbol or name attached only to that particular point.

Each test point should be labeled with the in-tolerance signal and tolerance limits which should be measured there.

Each test point should be labeled with the designation of the unit whose output is available at the test point.

If it is not feasible to present this information on the test point it should be included in job instructions and coded to the test point.

Test points should be an outstanding color so that they can be easily located in the equipment.

Luminescent markings should be used on test points (including selector switches and meters) so that they can be read in very low illumination.

CONNECTION TO TEST POINTS

No more than one full turn of a connector should be required to connect test equipment to a test point.

If maintenance procedures require that a test probe retain connection to a test point without being held by the technician, the test point should contain a quick-disconnect fastener to prevent the probe from falling out.

TEST POINTS FOR SHOP AND DEPOT

A test point (which may be nothing more than a bare wire) should be supplied at the input and output for each part or throwaway unit. One convenient way to provide these test points is to mount components on one side of a board and wiring on the other side with electrical connection through the board. Even if the wiring is mounted on the same side as the parts, test leads can be brought through to the back of the board. An advantage to having test points alone on a flat surface rather than in among the parts is that full identifying information for each test point can be stamped on the surface without being obscured by the parts.

Each wire should be labeled with a unique designation.

> This makes trouble shooting using wires easier because they are easier to identify. Provision should be made for technicians to label each wire they replace.

It should not be necessary to remove any assembly from a major component to trouble shoot to that assembly. This may require special test points on the major components or assemblies.

Test equipment and/or bench mock-ups should provide access to the outputs and inputs of each line replaceable unit through the normal interconnecting plugs. It should thus be possible for the shop or depot technician to check out each line replaceable unit without special test points being mounted on the unit.

SPECIAL CONSIDERATIONS FOR TEST POINTS FOR CHECKING AND ADJUSTING

Test points used in checking should be located close to controls and displays also used in the checking operations.

Each test point used in adjusting at the line, shop, and depot levels will preferably be directly associated with only one adjustment control. The signal available at such a test point should indicate unambiguously when the associated control has been moved to the required position. It should also be located so the technician operating the control can read the signal available at the test point.

Controls

Importance of Control Design to Maintenance

Controls are the means by which a maintenance technician or operator puts information into the equipment. Many of the controls used by technicians are the controls used by the operators of the equipment. Other controls will be built into the equipment strictly for maintenance. Maintenance controls include not only knobs and switches, but tool-operated controls such as screwdriver adjustments as well.

Because the design of controls is not unique to maintainability, a great deal of information on this topic is available in other sources. Consequently, only considerations judged particularly pertinent to maintenance are presented here.[1]

When a Maintenance Control is Needed

Special controls for maintenance must be designed into the equipment whenever the operator's controls cannot put information specified by maintenance procedures into the system.

The need for maintenance controls should be determined when procedures are first developed during design of the developmental model of the system. It will then be possible to make equitable compromises among circuit design requirements, effective control design and location, and maintenance procedures design if initial procedures require building of controls in unfeasible locations.

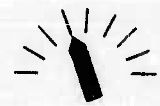
1. For details of control design see Ely, J. H., Thomson, R. M., and Orlansky, J. (Reference 2)

TYPE AND SHAPE OF CONTROL

Use hand-operated knobs in frequently used controls instead of a control requiring a tool to operate it.

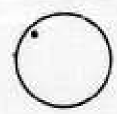
On-off switches: Use toggle switch.

Selector switches:
Use bar-shaped pointer.

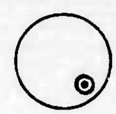


Continuous rotation for few turns:
Use round knob, no pointer.
Orienting dot may be useful for some purposes.
(Example: volume control)

volume



Continuous rotation for many turns:
Use round knob with crank. The crank should be hinged and fold into a recess in the knob when not in use.



Momentary contact switch: Use a spring-loaded pushbutton.

DIRECTION OF CONTROL MOVEMENT

Functions regulated by controls should increase when the control is moved clockwise, forward, or upward. Conversely, they should decrease when the control is moved counterclockwise, backward, or downward.

Toggle switches should be "ON" in the up or righthand position and "OFF" in the down or lefthand position.

CONTROL SIZE

The size of control knobs should increase as the force required to operate the control increases.

Make knobs for precision settings about two inches in diameter. Knobs for noncritical settings only need be about one inch in diameter.

Tool-operated controls should be operable by a screwdriver or other tool of medium size. Technicians are more likely to have a medium sized tool than a very large or a very small one.

When vernier controls are mounted on concentric shafts, the larger diameter should control the fine adjustment. This gives maximum precision.

LOCATION OF CONTROLS FOR MAINTENANCE

Units having operator's controls physically located on them:

Controls for maintenance should be located on the front panel behind an access door. (The operator's front panel will be accessible in the installation, ensuring that the maintenance controls will also be accessible.)

Units without operator's controls:

All maintenance controls should be located on one side of the unit. Use a side which will be accessible in the normal installation.

All units:

Locate all controls on the outside of the units. Ideally, all adjustments would be located on a single adjustment panel.

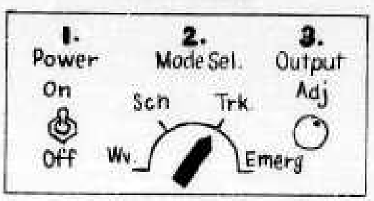
Locate all controls where they can be seen and operated without disassembling or removing any part of the installation.

> For example, do not put any controls under the pilot's seat, or where cabling will cover them.

Keep controls away from high voltage points and hot tubes. Use extension shafts if necessary.

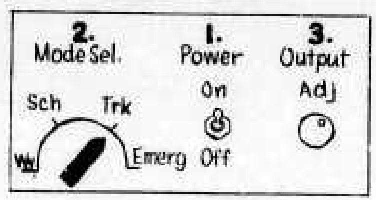
Place controls on the panel in the order in which they are to be used normally. This is particularly important for controls used in fixed procedures.

Use This



Assuming Order of use shown by numbers

Not This

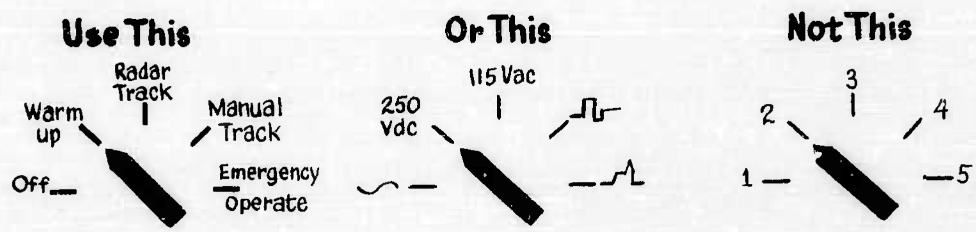


This recommendation should not be followed if it will cause conflict with the operator's procedures.

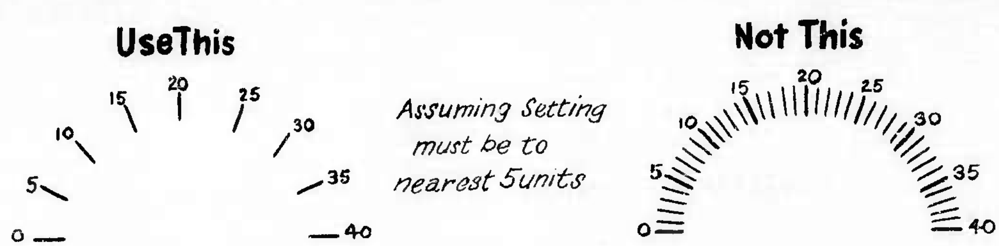
If screwdriver-operated controls must be inside units, bring controls as near to the outside of the unit as practicable. Use extension shafts if necessary. Provide accesses and guide shafts surrounding the screws.

CONTROL SCALE MARKINGS

Position markings should be descriptive rather than coded. The markings should describe a condition, an action, or an indication.



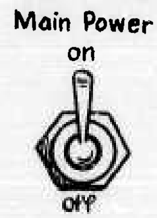
Scales on controls should be only fine enough to permit the required accuracy in setting. In general, interpolation should not be required, nor should extra scale markings be included.



LABELING AND CODING CONTROLS FOR MAINTENANCE

Every control should have a name and be labeled with that name.

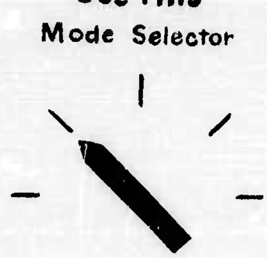
Use This



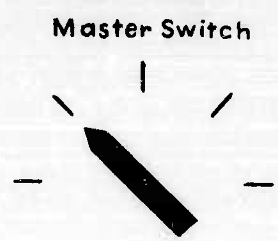
Not This

Labels should state the function of the control.

Use This



Not This



Controls should be numbered in sequence of their operation whenever they are used in a fixed procedure. (This number should be used in addition to the name label.)

See illustration on page 86.

CONTROL FORCE

Controls should have smooth, even resistance to movement except for detents on selector switches.

Multi-position selector switches should have sufficient spring-loading so that a switch cannot inadvertently be left between detents.

Push buttons should not be so heavily spring-loaded that they cause uncomfortable pressure against the finger.

Displays

Importance of Display Design to Maintenance

Displays tell the technician whether the total system and its various units are operating within tolerance. If adequate displays are not provided, the technician's tasks of checking, adjusting, and trouble shooting the system are more difficult.

Displays provided for the operator are used for maintenance as well as those built in only for the maintenance technician. Most of the principles which apply to the design of operator displays also apply to the design of special maintenance displays.[1] Only considerations especially pertinent to maintainability are presented here.

TYPE OF DISPLAY

All-or-none type of displays should be used in cases where they will convey sufficient information.

> Use a tel-light if it will do the job, instead of a meter.

Use loud auditory signals to supplement tel-lights for displays which are not constantly watched when it is important that changes in their indication be noted immediately.

> Example: Personnel on maintenance duty usually do not immediately notice the signal light come on when the high-voltage overload relay kicks out on a certain ground equipment. A horn or bell would demand immediate attention.

---

1. For details of display design see Baker, C. A. and Grether, W. F. (Reference 1)

Use moving pointer-fixed scale visual indicators for most maintenance indications. This is the best all-around type of indicator for checking, setting, tracking, and quantitative reading tasks.

Where center null displays are used, circuit design could be such that if power fails the indicator will not rest in the in-tolerance position.

DISPLAY MOVEMENT

The value of a particular function should increase as a pointer moves clockwise past a fixed scale or as a moving scale moves counterclockwise past a fixed pointer.

LOCATION OF DISPLAYS

Displays should be located in such a way that they can be read with minimum time and error in the normal course of maintenance activity. Ideally, all displays should be on a single panel of the equipment. When practical considerations prevent this, the locations of displays should be determined by studying the maintenance procedures and hardware configuration. These will tell when a display is needed and where the technician will be at that time.

Units with operator's displays physically located on them:

Locate maintenance displays behind an access door on the operator's panel.

> The displays should be placed on the operator's panel because it will be accessible.
>
> They should be covered so as not to confuse the operator.

Units without operator panel:

Locate maintenance displays on one face of the equipment which will be accessible in a normal installation.

All units:

Locate displays so that they can be observed without disassembly or removal of any portions in the installation.

Locate displays used in system check-out so that they can all be observed from one position. This may involve tilting displays located in low or high places.

DISPLAY SCALE MARKINGS

Minimum information:

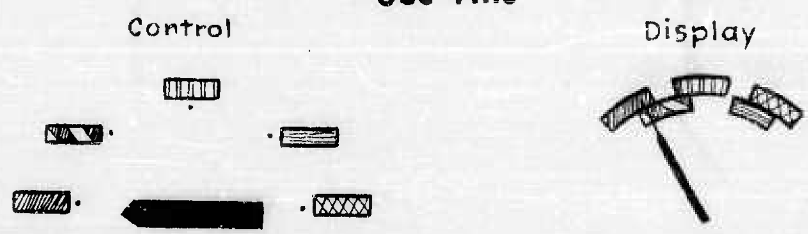
Display scales should contain only information needed by the technician to make a decision or take some action. Extra information clutters the picture.

> For example: A meter with a green strip to show the in-tolerance reading is preferable to one on which the technician must read the actual value, if the exact value is not needed.

Tolerances:

Display scales should show the correct reading and the tolerance for the reading. A single center scale colored area for in-tolerance is best. If more than one reading must be obtained from a single display, colored areas correlated with colored control settings can indicate the in-tolerance ranges. Use of colors requires good display illumination.

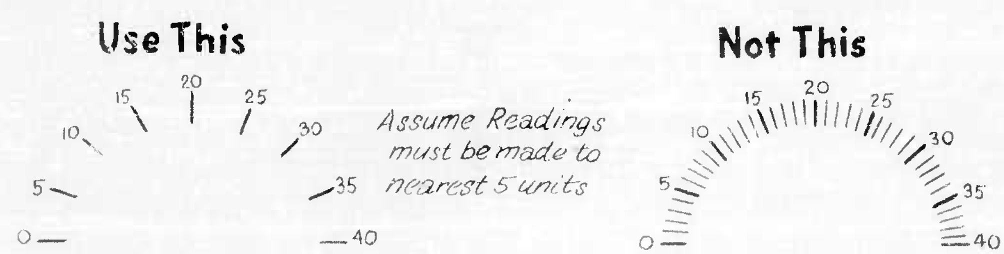
Use This



Fineness of scale:

Display scales should have only enough graduations for the required accuracy to be obtained without interpolation.

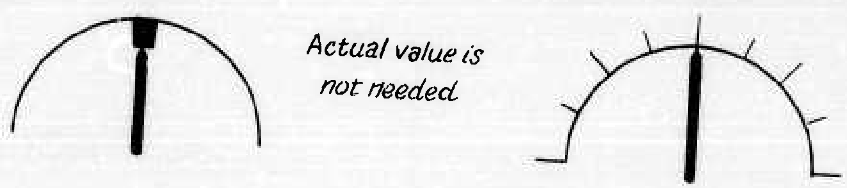
Scales which are too fine clutter the picture.



Remember, however, that calibration may be useful for recording readings from periodic checks to discover deteriorating conditions as well as to make a decision from a single check at a particular time.

Use a numerical scale only when the technician actually needs quantitative information; otherwise use areas marked with tolerance ranges.

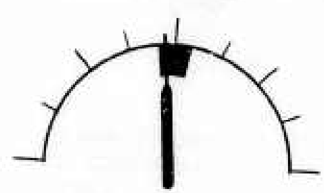
Use This **Not This**



Special calibration points should be provided either on the dial face or on a separate overlay if the edges and midpoint of the tolerance range are not sufficient for accurate calibration of the dial.

If a display must provide numerical information for some operations and only an in-tolerance or out-of-tolerance indication for others, both types of display markings should be used.

Use This



LABELING OF DISPLAYS

Labels should tell what functional quantity the display indicates rather than what electrical characteristic is indicated.

Use This	Not This
Transmitter Output	Power
+300V Supply	Voltage
Magnetron Current	Milliamps

Labels should tell where the displays fit into the block diagram of the system or unit.

Use This	Not This
NS rate servo output	Rn
Turret drive motor voltage	115 V
TAS transmitter output	Rt

BRIGHTNESS OF DISPLAYS

Internal displays should be lighted where necessary.

Internal areas of equipments are frequently almost "blacked out" by surrounding portions of the system or other equipment nearby. Displays which must be located in such areas should be lighted so they can be read by the technician. The nature of the installation must be considered when making these decisions, rather than the components taken individually.

Control-Display Relationships

Importance of Control-Display Relationships to Maintenance

The relationship between control and display can affect the speed of control setting, errors made during the setting, and accuracy of the final setting. Its effect is more pronounced when tasks must be performed under time stress.

RELATIVE LOCATIONS OF CONTROLS AND DISPLAYS

Each display should be mounted directly above the control affecting it.

Each display should be placed so it can be read with the required degree of accuracy by the technician operating the controls affecting the display.

All controls and displays used in a given procedure should be located on the same panel.

CONTROL-DISPLAY RATIO

(amount of display change for given control change)

Fine adjustments required: large movement of the control should yield small movement of display.

Wide range of display movement required: small movement of control should yield large display movement.

Where a wide range of display movement may be required but the end setting must be precise:

A crank may be provided on a round control to facilitate rapid turning.

The ratio of control-display movement may be kept at a medium value.

Both a coarse and a fine setting control might be provided for a single display. Coaxial mounting will probably be most convenient.

CONTROL-DISPLAY LABELING

Display labels and control labels should be collated so that the display label suggests which control(s) affect the display.

Use This		Not This	
Control	Display	Control	Display
"Transmitter output adjust"	"Transmitter output"	"Power adjust"	"DB out"

CONTROL-DISPLAY MOVEMENT

Make the direction of display movement correspond to the direction of movement for its related control.

Direction of Movement When Function Increases

Control	Display (in order of preference)
Clockwise	Clockwise Right Up
Forward	Clockwise Right Up
Up	Up Clockwise Right
Right	Right Clockwise Up

Installation of Prime Equipment

Importance of Installation to Maintainability

An excellent design for maintainability can be counteracted almost completely by a poor installation which blocks technicians from performing specified maintenance.

GENERAL REQUIREMENTS FOR A GOOD INSTALLATION FOR MAINTAINABILITY

A good installation for maintainability is largely a matter of accessibility--can the technician get to the equipment rapidly and easily as required by his job.

Maintenance procedures will indicate the portions of the equipment to which access is required for each level of maintenance. The installation must be compatible with these requirements. For example, if trouble-shooting checks must be made in a junction box, the box must be readily accessible. On the other hand, there is no need for the line technician to have access to the insides of units that are to be worked on only in the shop.

Design features of the equipment and maintenance procedures must be compatible with technical limitations of a given installation. For example, if the space configuration available for installation permits only one face of a unit to be accessible, all controls, displays, cables, check points, etc. must be on that face. Close coordination is required between the equipment designer and the builder of the installation facility. See Section 2, "Coordinating Design for Maintainability."

STEPS IN PLANNING AN INSTALLATION

1. Determine what technical limitations are imposed.

   How much space is available and in what shape?
   How must the weight be distributed?
   What will be the physical sizes and weights of the various equipment units?
   What are the restrictions on cable lengths?
   What access panels or doors will be available?

2. Determine what maintenance operations the technicians will have to perform on any portion of the equipment <u>while it is installed</u>.

   Which units will the technician need access to?
   What sides of these units must be accessible?
   What units need servicing, or are likely to be replaced often?

3. Deduce from 2 above what the needs are for access to the various units of the equipment.

4. Specify an installation compatible with technical limitations and needs for access.

   Decisions should be coordinated between the installation builder and equipment designer.
   See Section 2.

5. Request a change in either technical limitations or maintenance procedures if technical limitations force an installation which will make maintenance difficult.

ACCESS TO UNITS

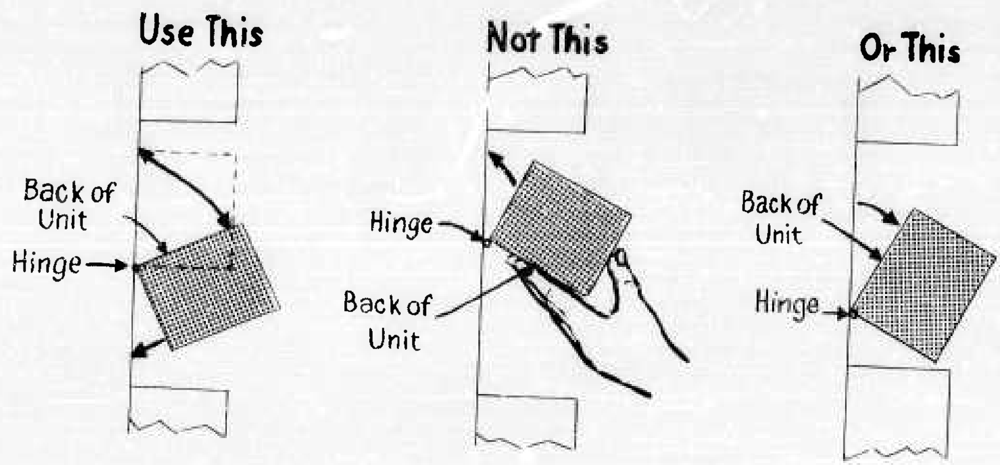
Removal of any particular line replaceable unit should require opening only one access panel in the installation.

Locate units so no other equipment has to be removed to gain access to them. When it is necessary to place a unit behind other equipment:

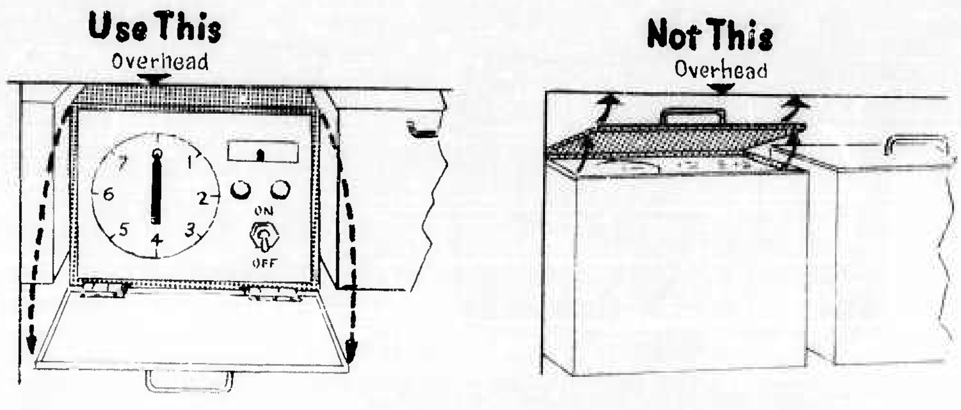
> The unit requiring less frequent access should be in the back.
>
> Units maintained by the same technician should be placed one behind the other because considerable time may be wasted in getting a different technician to remove an obstructing unit. There have been instances, for example, where electronics personnel have had to request armament personnel and engine mechanics to remove obstructing equipment.

Units should not be placed in recesses, or behind or under stress members, floor boards, operators' seats, hoses, pipes, or other items which are difficult to remove unless this serves some functional purpose such as protecting the unit or is <u>necessary</u> for some other reason.

Hinge mounted units for which the line technician must have access to the back should be free to open their full distance and remain open without being held.

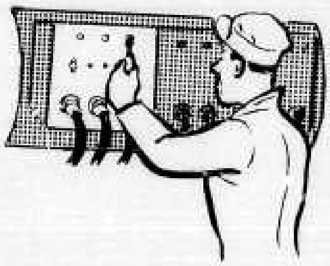


Bulkheads, brackets, other units, etc., should not interfere with removal of covers of units within which work must be done at the line level.

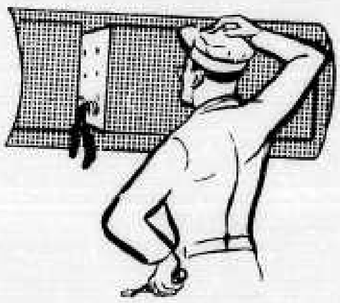


Check points, adjustment points, cable-end connectors, and labels should face the technician. They should not be hidden by other units.

Use This



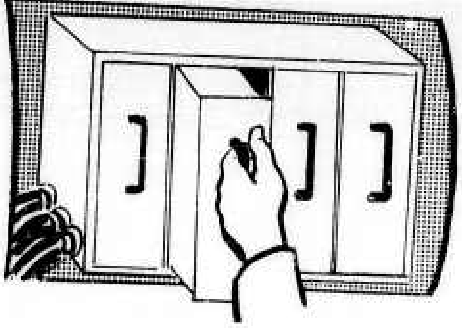
Not This



Removal of units through the front of the operator's panel is likely to be easier than removal from the back, because more space is usually available at the front.

Locate major units so that line replaceable subunits can be removed from them without removing the major units from the installation.

Use This



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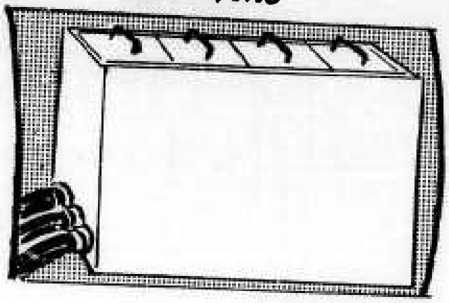


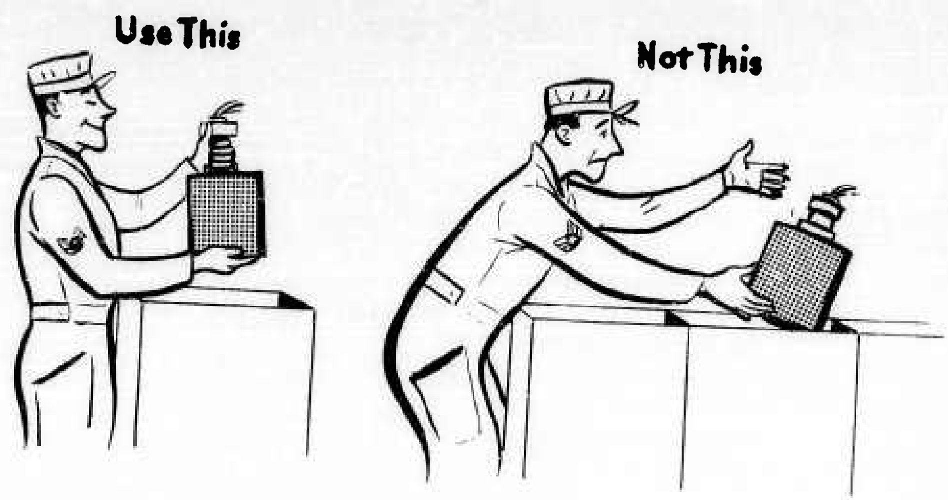
HEIGHT, SPACE, WEIGHT CONSIDERATIONS

Work space requirements: See "Physical Dimensions of Maintenance Personnel" in Section 2, page 10.

Weight limits for various heights of installed units: See "Weight Lifting Capacity" in Section 2, page 12.

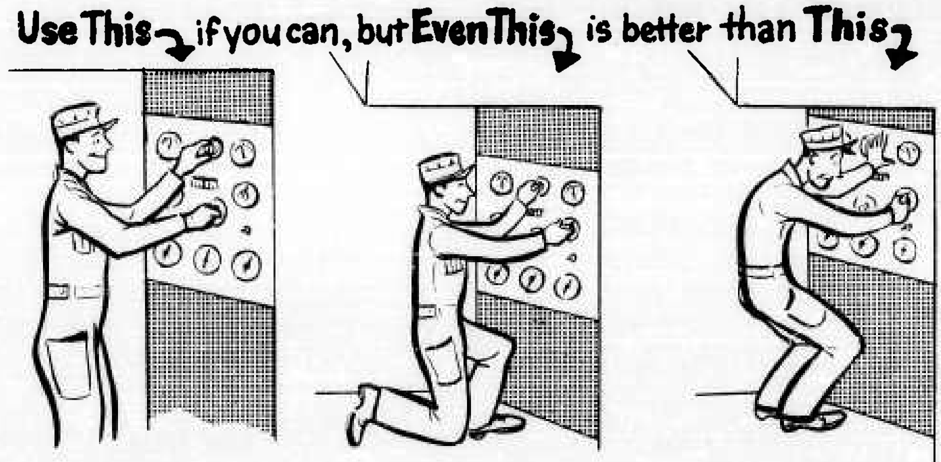
Technicians should not have to reach out for heavy units (more than about 25 pounds).

> Although almost any adult male can lift 100 pounds or more (assuming it is of convenient size and shape) if it is close to him, there is evidence that even 35 pounds is too heavy to be handled carefully at distances of 24 inches or more from the body.



The position required of the maintenance technician while working on each unit should be studied and the installation designed accordingly.

What may look like good accessibility from casual observation may require the technician to hold an extremely awkward position.



The best heights (in feet from the floor) for straight work on components for various positions of the technician are suggested below.[1]

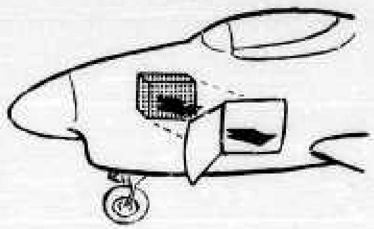
Position	Approximate heights of controls, etc.
Technician standing on the floor	3 - 5 feet
Technician kneeling on the floor	2 - 4 feet
Technician sitting on the floor	1 - 3 feet

1. Based on a few informal measurements by the authors.

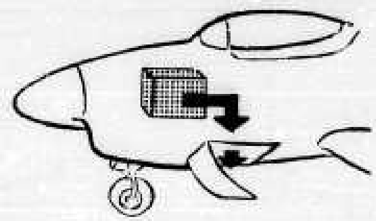
PROVISIONS FOR REPLACING UNITS

Units should be removable from the installation along a straight or moderately curved line rather than through an angle.

Use This



Not This



Line replaceable units should be independently mounted to the housing rather than being attached to each other so it is necessary to move only the unit to be replaced.

Provisions should be made for support of units while they are being removed or installed.

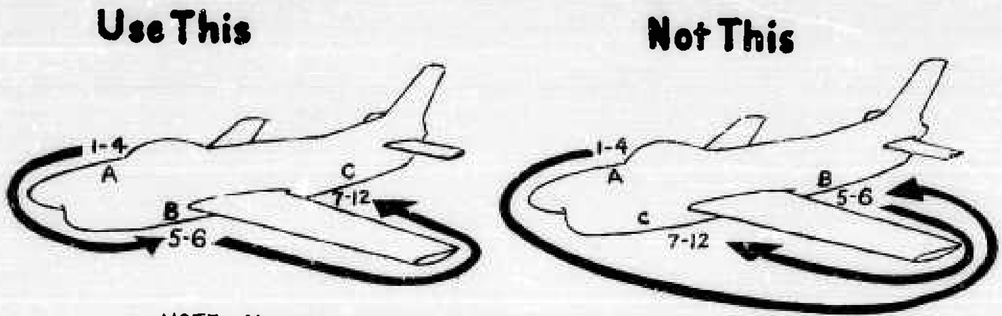
Handles and grips should be positioned so they can be held comfortably while the unit is being removed or replaced. Handles and grips should not be in a position where they are likely to catch on other units, wiring, or structural members.

Use This

Not This

Note: Heavy units should have recessed handles near the back to facilitate handling.

Units should be laid out so technicians are required to do a minimum of moving from position to position during system checking in the installation.



NOTE: *Numbers indicate preflight steps; letters indicate positions of mechanics*

Equipment should be installed so that complete preflight can be made without using special stands or ladders.

Junction boxes should be very accessible if line trouble-shooting procedures require their use as test points. If other test points are available, however, the junction boxes may be relatively inaccessible since they usually require very little maintenance.

Units which require frequent visual inspections, e.g., desiccators, should be installed in positions where they can be seen easily without removing panels, covers, or especially other units.

Locate junction boxes and terminal strips so that they provide a convenient source of check points while the equipment is in operation.

> These items may permit considerable checking without having to disconnect any components of the prime equipment or interfering with its functioning. Use of junction boxes and terminal strips for check points requires that each check point be accessible to test equipment leads and clearly labeled. It also requires that maintenance instructions and diagrams indicate the location (functional and physical) and use of these points.

OTHER CONSIDERATIONS

Provision should be made for easy passage of replacement cables with their attached connectors through walls, bulkheads, etc.

> There have been instances in which it has been necessary to unsolder 20 or more pins to remove a connector in order to pass the cable through an opening. In other cases, holes have had to be enlarged or new ones drilled.

Units should be located in positions where oil, other fluids, or dirt is not likely to drop on them or on the technician during maintenance.

Power cables should not be routed through switches which personnel in remote locations are likely to switch off or on inadvertently while the equipment is being checked.

Test Equipment

Selected recommendations on designing test equipment for optimal operation are presented in this segment. Design of test equipment for maintainability follows the same principles as designing prime equipment for maintainability.

More detailed recommendations on human engineering of test equipment can be found in Spector, P., Swain, A. D., and Meister, D. Human Factors in the Design of Electronics Test Equipment. RADC Technical Report 55-83, April 1955 (Reference 7).

DEFINITIONS

Built-in test equipment: is an integral part of the prime equipment. It may be a complex automatic checker or a simple voltmeter with external leads.

Go, no-go test equipment: provides only one of two alternative answers to any question. It tells only whether a given signal is in or out of tolerance.

Automatic test equipment: checks two or more signals in sequence without the intervention of a technician. The test usually stops when the first out-of-tolerance signal is detected.

Collating test equipment: presents the results of two or more checks as a single display. For example, a light may come on only if a number of different signals are in tolerance.

GENERAL CONSIDERATIONS

Simplifying the job of the prime equipment technician by providing built-in, automatic, go, no-go, collating test equipment will not necessarily reduce the over-all maintenance load. However, elaborate test equipment can reduce preparation time or turn-around time of prime equipment, as with missiles and interceptor aircraft. In effect, the maintenance load is shifted back one stage from the prime equipment. Problems in maintaining complex test equipment can offset their advantages in maintaining prime equipment.

Built-in, go, no-go, automatic, and collation features are all virtually independent of each other. Thus, a given test equipment may have all, none, or some of these features in any combination. Also, a given test equipment may be partially built-in, partially go, no-go, etc.

In general, it is recommended that built-in, go, no-go, automatic, and collation features be used. However, for each system the relative importance of the advantages and disadvantages of each feature must be judged in view of the demands that will be placed upon the equipment and maintenance personnel in the field.

Built-in test equipment:

Advantages	Disadvantages
Less likely than portable test equipment to be lost or damaged.	Likely to add to the weight and space requirements of the prime equipment; a very strong disadvantage in airborne equipment.
Available when needed.	More built-in test equipment may be required because a separate item is usually required for each prime equipment.
No special storage facilities are required.	

Transportation to the prime equipment for use in maintenance is not required.

Transportation of built-in test equipments to a point for convenient calibration may be more difficult than transportation of portable test equipment.

Permanent installation of the test equipment may increase the complexity of wiring for the system and may even increase the amount of required maintenance for the prime equipment.

Go, no-go test equipment:

Advantages	Disadvantages
Presents information that is clear and unambiguous.	Unique circuitry usually required for each signal value to be tested. Sometimes, however, ordinary displays can be converted to go, no-go by appropriate use of reference scales such as a colored section on a meter dial.
Usually easy to read.	The increase in the number and complexity of circuits usually required adds to initial cost and development time; it is also likely to increase the rate of test equipment breakdown.
Can simplify difficult tasks such as balancing circuits or checking complex waveshapes.	

Except in long, fast check sequences, go, no-go equipment is of relatively little help to the technician in checking common voltages or simple waveshapes.

Likely to require modification when prime equipment is modified. A special model may be required for each model of prime equipment.

Automatic test equipment:

Advantages	Disadvantages
Can make a rapid sequence of checks with little or no chance of omitting any steps.	Cost, size, weight, and maintenance requirements are relatively high.
	This type of equipment is relatively specialized, with little versatility.
	Must almost necessarily have self-checking features to detect test equipment malfunctioning. This adds to cost and to problems of maintaining the test equipment.
	More likely to require modification when prime equipment is modified. A special model may be required for each model of prime equipment.

Collating test equipment:

Advantages	Disadvantages
Reduces the number of displays the technician must read, thereby reducing check time and probably reducing errors.	Similar to those for go, no-go and automatic test equipments.

Collating test equipment should indicate not only that all signals are or are not in tolerance; it should also provide an indication of which signal, if any, is out of tolerance. If only the collated display is presented, the equipment will not be an aid to trouble shooting.

DIFFICULTY OF USE

Assess the difficulty of operating a proposed test set early in its development (certainly not later than building of a non-functional mock-up) by having typical personnel "walk through" the operating procedures.

Indications of too-difficult operation are:

Personnel who are reasonably proficient at operating other test equipments have to acquire extensive new skills in order to operate the tester being developed.

Personnel make errors in operating the tester even when following written instructions.

To simplify use of test equipment:

Minimize the number of controls and displays.

Reduce the number and complexity of steps required for operation. This can be done by "ganging" certain setup controls and/or making certain sequences of operations automatic.

Clarify instructions. See Section 5 of this guide.

CONTROLS AND DISPLAYS FOR TEST EQUIPMENT

Exact indications should be presented on test equipment displays, rather than requiring multiplication or other transformation of display values.

If transformation of display values is required, a conversion table should be provided on the test equipment.

If it is not feasible to provide a conversion table, each transformation factor should be indicated beside each switch position or display scale requiring the use of that factor.

Use decimal transformation factors to simplify arithmetic requirements.

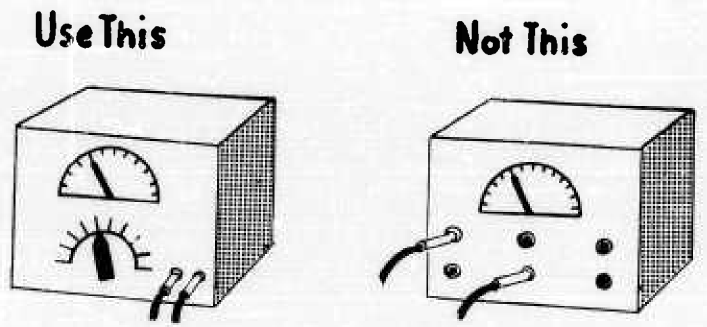
Only the scale being used at a given time should be in the technician's view.

This eliminates the possibility of reading the wrong scale. Whenever more than one scale must be in the technician's view, they should be clearly differentiated from each other by labeling and color coding to their respective control positions.

Provide devices such as warning lights, power switches which close automatically when the test equipment lid is closed, and written warnings which ensure that test equipment will be turned off when testing is completed.

Design all controls and displays in accordance with recommendations under "Controls," "Displays," and "Control-Display Relationships" on pages 83 to 99 and in suggested references.

Provide selector switches on test equipments instead of requiring plug-in connection. Selector switches require less time to select the proper function and eliminate the possibility of leads falling out of the receptacle.

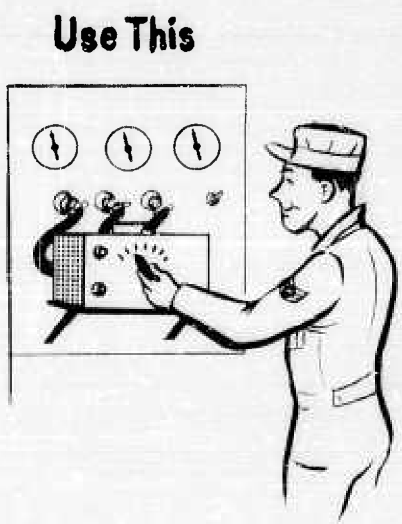


PROVISIONS FOR STORAGE AND HANDLING

Portable test equipment should be rectangular in shape for convenient storage.

Handles on the outside case of portable test equipment should be recessed or hinged so they do not take up excessive storage space.

Provision should be made for setting test equipment down while it is being used. Even light equipments may be cumbersome to hold while checks are being made.



PROVISIONS FOR TEST LEADS AND ADAPTERS

Provide adequate storage space in the lid or cover of test equipment for storage of removable items such as leads and adaptors. Indicate the proper locations for the various items that go into the storage space.

Provide fasteners or holders in storage compartments for accessories to prevent damage to the test equipment or accessories.

Test leads should require no more than a fraction of a turn for attachment to prime equipment receptacles, unless attachment is permanent.

Whenever adaptors must be used, they should be a part of the test equipment removable items. This prevents their loss, reduces probability of their being damaged, and saves time in setting up the test equipment.

OTHER CHARACTERISTICS

Windows for test equipment dials should be as break and scratch resistant as possible.

A signal showing when the test equipment is warmed up should be provided. If it is not feasible to present such a signal, the warm-up time required should be clearly indicated near the warm-up switch.

A simple check should be provided to indicate when the test equipment is out of calibration or is otherwise malfunctioning. There should be a simple way to put the test equipment into calibration.

The outer case and all removable parts (e.g., adaptors, leads) of test equipment should be clearly labeled with their official Air Force nomenclature. Purpose of the tester and special cautions in its use should also be indicated.

Every item which the technician must recognize, read, or manipulate (dials, knobs, switches, lights, etc.) should be labeled.

Provide devices such as circuit breakers and fuses which will safeguard against damage if the wrong switch or jack position is used.

Instructions for using a test equipment should be stored in its lid or in a special compartment in the tester to ensure that the instructions are always available. A checklist for operating the test equipment might be printed on a metal plate and attached to the equipment.

Bench Mock-Ups

USE OF BENCH MOCK-UPS

The term bench mock-up is used here to mean a prime equipment set up in a maintenance shop or depot to check and/or trouble shoot units brought in from the line. A mock-up may consist of an entire system or only a portion of a system. Either type may be provided with signal generators and dummy loads to simulate inputs from and outputs to the physical environment (e.g., radar waves).

Mock-ups are used in trouble shooting by replacing a unit of the mock-up with a unit suspected of containing a malfunction. The remaining portions of the mock-up are then used to feed signals into and receive signals from the suspected component. If a malfunction symptom appears when the suspected unit is installed, but not when the regular mock-up unit is installed, it is concluded that the suspected unit is malfunctioning.

GENERAL CONSIDERATIONS IN DESIGN OF MOCK-UPS

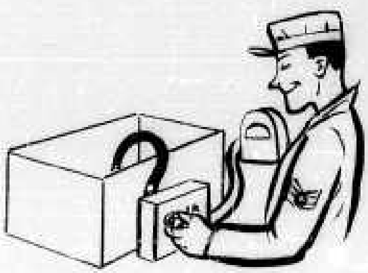
Bench mock-ups should be factory built. They should be designed as if they were an item of test equipment, to expedite shop and depot maintenance procedures. Mock-ups are constructed essentially from production units of the prime equipment. Signal generators, dummy loads, extra junction boxes, or special cabling, terminal strips, test points, cases, controls, or displays may be required, however, for the mock-up to be maximally useful for maintenance. If technicians must construct their own mock-ups in the field from spare prime equipment units and spare bits and pieces locally available, they may have difficulty in providing these desirable features.

The equipment designer will probably be in the best position to integrate the mock-up into total maintenance of the prime equipment. For example, he may be able to provide more specific written maintenance instructions if exact design of the mock-up is known.

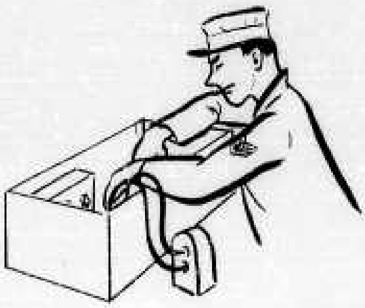
CABLING OF BENCH MOCK-UPS

Extension cables should be provided for subunits so they can be removed from the larger units for functional checking.

Use This



Not This



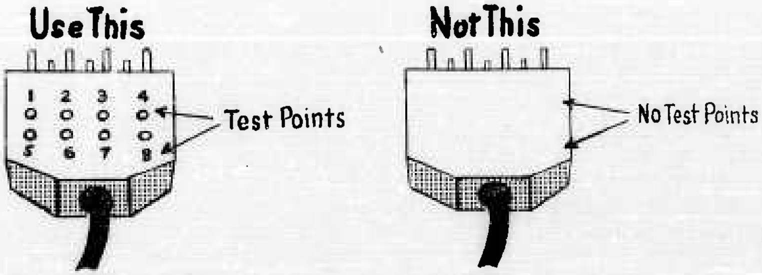
End connectors on all mock-up cables should require only a strong push or a pull to connect or disconnect them.

> Mock-up cables need not withstand strong vibration or shock. Because of the way in which mock-ups are used, however, they do need to be connected and disconnected frequently.

Provide extra heavy coverings on mock-up cables (for example, vinyl tubing) to protect them from wear resulting from frequent connection and disconnection.

Mock-up cables, including extension cables for subunits, should provide a test point to check the signal flow through each wire.

> Usually this can be done effectively at the connector pins. In some cases it may be more convenient to provide certain of the test points on junction boxes or terminal strips. Each test point should be clearly labeled. Job instructions for the mock-up man should give correct signal values and tolerances for each test point.

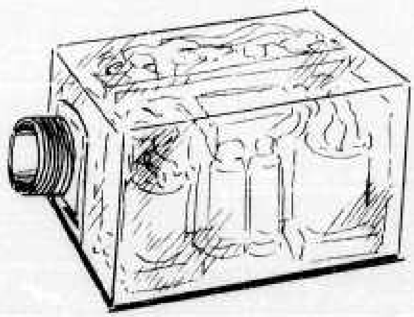


When an assembled mock-up is not provided, supply a set of cables for interconnecting the equipment units to aid field personnel in setting up the mock-up.

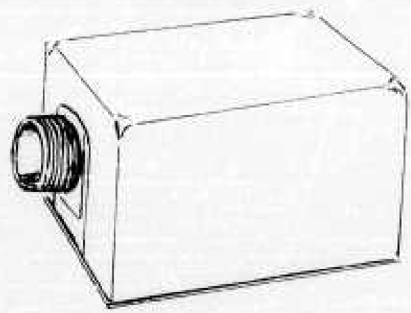
COVERS AND CASES FOR MOCK-UPS

Mock-up units containing parts whose operation may be checked visually should have transparent plastic covers rather than metal covers if electrical shielding is not necessary.

Use This



Not This



Packing cases for mock-ups and maintenance test benches should be of a permanent type, preferably of light weight metal. They should serve as a bench for the enclosed equipment when unpacked.

Necessary hardware such as handles, hoisting lugs, casters or runners, and handling gear should be a permanent part of the cases.

These cases must meet physical requirements for transportability as specified for the system.

Design of mock-up cases should permit rapid packing and unpacking of mock-ups for mobility under combat conditions.

See also "Covers and Cases for Equipment Units," page 53.

LAYOUT OF MOCK-UPS

Mock-up units should be stacked in a configuration which makes every unit accessible without removing any other unit.

Layout of mock-ups should provide adequate space for use of test equipment, including space for setting test equipment down while it is being used.

Tools

Tool requirements are directly derivable from consideration of necessary maintenance operations and the design characteristics of the equipment involved. Tools must be specified and/or designed as an integral part of designing for maintainability.

Neglecting consideration of tool requirements until equipment design and procedures are final is likely to result in a need for many special tools or an unnecessarily wide variety of standard tools.

Each equipment system should be accompanied by a comprehensive list of tools needed for all maintenance tasks. All tools on this list should be tried out during developmental testing of the system to uncover duplications and omissions, and to discover equipment design features that require more tools than necessary. One small unit seen in the field had slotted screws, allen-head screws, and hex-head screws on the front panel alone.

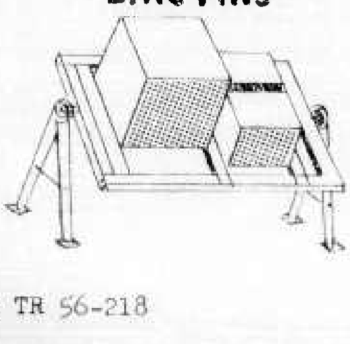
Requirements for special tools should be kept to a minimum.

The variety of tools required should be minimized.

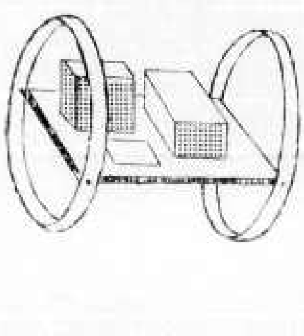
Metal handles should be avoided on tools that are likely to be used in extreme cold.

Special holders should be provided in the shops for units which may be damaged if they are set down on their tops or sides.

Like This



Or This



A special guide tool which attaches to the access should be provided when an adjustment control under the access would otherwise be difficult or dangerous to locate.

Specify or design tools that are compatible with the design of the equipment on which they will be used.

> Example: Maintenance technicians frequently report that they are issued only large soldering irons to work on wires which are in close proximity to other wires or parts. This results in considerable difficulty on tasks which would be easy if small soldering irons or soldering guns were available.

> Example: Maintenance technicians in one shop were issued a spanner with a solid shaft. This spanner could not be used for its intended purpose of removing clutches from motors because the motor shafts prevented the spanner from being brought down so the pins could be inserted in the holes in the clutches. In this case, field technicians fabricated a spanner with a slotted shaft to do the job.

Prior examination of the equipment on which these tools were to be used would probably have caught these discrepancies.

Specify or design tools that are compatible with the job to be performed.

> Example: Line technicians for one equipment were issued a set of sockets with a screwdriver-type round handle to remove bolts which were frequently tight and sometimes slightly rusted. Technicians had great difficulty removing these bolts because not much torque could be exerted on the bolts using this type of handle. A lever handle should have been provided.

Prior examination of the task requirements would probably have uncovered this discrepancy.

Screwdrivers should have clips to hold free screws which cannot easily be held with the fingers.

A given tool should be designed for as many different uses as possible, but only insofar as this is compatible with the tasks for which it is intended.

> Example: One adjustable wrench may serve the function of a large number of fixed-sized wrenches. However, an adjustable wrench may not be as satisfactory as a fixed-sized wrench for removing bolts in restricted space.

Tools which must be used near high voltages should be adequately insulated at the handles and other parts of the tool which the technician is likely to touch.

Magnetic tools should be avoided if they will interfere with the operation of delicate circuits.

Screwdrivers for small-sized adjustment screws should be provided with a funnel-like shield which will aid placement of the screw-driver on the adjustment point and prevent it from slipping off.

Provide a speed tool whenever screws must be rotated through many revolutions if downward force on the equipment will not be harmful.

Ratchet-type tools are usually very useful because Air Force technicians must usually work in a limited space.

Tools for line technicians should have a dull finish so they do not reflect glare in strong sunlight.

section 5

Recommended Characteristics for Maintenance Procedures And Job Instructions

OVERVIEW

This section is divided into two major subsections. The first deals with the design of maintenance procedures, and the second with means of presenting these procedures and maintenance diagrams.

Many of the ideas presented in this section have not yet been verified through application to the design of weapon systems. Also, many of the recommendations in this section are contingent upon the design characteristics of the equipment to which the procedures would be applied. Consequently, it has not been considered desirable to make this section as prescriptive as the previous sections, particulary Section 4. Rather, many of the ideas in Section 5 are presented as ideas to be considered and tried out by the designer in those cases where they may be applicable. In effect, this section presents tentative, but concrete recommendations for preparing some of the procedures called for in the Design Schedule for Maintainability in Section 3, and for presenting them to the technician in maximally usable form.

Considerations in Preparing Procedures

Importance of Good Maintenance Procedures

Maintenance procedures specify the activities of the technician and therefore indirectly determine what maintainability features must be built into the prime equipment and what maintenance supports are needed.

Poorly designed procedures can offset the benefits of otherwise good design for maintainability. Delaying preparation of procedures until after the equipment is designed is likely to yield poor maintainability.

Procedures Needed for Maintenance

Every maintenance operation should be specified in procedures. These procedures should be prepared during system development according to the schedule contained in Section 3.

Procedures are required for each task in:

Line maintenance Shop maintenance Depot maintenance Periodic maintenance	for	Inspecting Checking Trouble shooting Adjusting Replacing Repairing Servicing

Recommendations for the design of all types of procedures are presented under "General Considerations" below. Specific recommendations for the design of checking and trouble-shooting procedures are presented in the following section, "Considerations in Preparing Checking and Trouble-Shooting Procedures," because field observations have suggested that these maintenance functions are in the greatest need of improvement.

General Considerations

Keep procedures as brief as possible, particularly for the line level.

Remember that new technicians may require procedures more detailed than would be required by highly trained and skilled technicians.

Keep the number and complexity of decisions required of the technician to a minimum.

Require use of the minimum possible number and variety of tools and test equipments.

Make the series of steps in a procedure as invariant as is compatible with efficiency.

Specify for each procedure the condition the equipment should be in (e.g., proper control settings) prior to beginning the procedure. Specify how to set up equipment for the procedure and how to shut down equipment after the procedure.

Provide procedures which do not require working near dangerous voltages or unprotected delicate components.

Provide servicing procedures which, insofar as possible, can be performed through accesses rather than requiring dismantling of equipment.

Considerations in Preparing Checking and Trouble-Shooting Procedures[1]

Need for Systematic Trouble-Shooting Procedures[2]

It is especially important that systematic trouble-shooting procedures be provided. Technicians will frequently use inefficient or even dangerous practices if efficient procedures are not provided.

Overview of Systematic Trouble Shooting

Systematic trouble shooting should proceed in the following three phases:

1. Routine check of system to identify or verify malfunction symptoms.

2. Analysis of symptom pattern to narrow the area of malfunction.

3. Special checks to isolate the malfunction to a replaceable or repairable unit.

1. An example of an integrated group of checking and trouble-shooting aids is presented on pp. 148 to 156.

2. A full discussion of systematic trouble shooting is presented in: Miller, R. B., Folley, J. D., Jr., and Smith, P. R. (Reference 4)

   A portion of the above report is reproduced as: Miller, R. B., Folley, J. D., Jr., and Smith, P. R. (Reference 5)

ROUTINE CHECKS

Routine checks are those which are regularly used to determine if an equipment or a prescribed portion of an equipment is operating properly or is malfunctioning. They may be differentiated from special checks which are used only for trouble shooting to determine which component within the equipment is malfunctioning.

Trouble shooting will usually begin with a routine check. It will tell the technician that a malfunction is present within the system and will provide information as to where within the system the malfunction is located. This information is in the form of a pattern of malfunction symptoms. Analysis of these symptoms may eliminate the need for certain special checks.

ANALYSIS OF SYMPTOM PATTERNS

One way to help the technician analyze symptom patterns is to provide him with special diagrams which indicate which components affect each system output for each step of the routine check procedure. Which components have come into or gone out of operation since the previous step should be indicated. The technician can use these diagrams to "figure out" which components could be causing a certain pattern of symptoms.

It is probably more useful, however, to provide a diagram for each symptom pattern showing the data flow among possible malfunctioning components. If such diagrams cannot be provided, a list of possible malfunctioning components and special checks which should be made for each symptom pattern is also useful.

Where the number of different symptoms which may be observed from a particular routine check is n, the number of possible patterns is 2^n-1. Thus, even where the number of different symptoms observable from a routine check is relatively small, the number of patterns may be too large to provide analyses for all of them. For example, 10 different symptoms can yield 1023 patterns.

There are two major ways of reducing the number of different patterns which must be analyzed. Both involve working with groups of symptoms and both will not, usually, make full use of the information available from the routine check.

The first way is to combine a number of individual symptoms into a single group symptom. The group symptom is considered to have occurred if any of the individual symptoms in the group occurs. A diagram is then prepared for each pattern of group symptoms showing the data flow among all of the components in which a malfunction could cause the observed pattern of group symptoms. No information available from the routine check is lost by this method when the same components could cause all of the individual symptoms in a particular group.

The second way to reduce the number of symptom patterns is to divide the individual symptoms into groups and then prepare a diagram only for each within-group symptom pattern. Thus, if nine symptoms were divided into three equal groups, the designer would prepare $2^3 + 2^3 + 2^3 - 3$ or 21 different diagrams instead of the 2^9 or 511 diagrams for all possible patterns for individual symptoms. No information available from the routine check is lost by this method when no component could cause symptoms in more than one group. An example of this method is shown on page 153.

SPECIAL CHECKS

Provide the technician with aid in choosing the best sequence of special checks to use after the symptom pattern has been analyzed.

The sequence of checks should usually be flexible, with the exact sequence depending upon where malfunction symptoms are observed.

> Exception: An inflexible order of checks can be specified where the time required for a particular sequence is likely to be small. This is usually the case only in trouble shooting to parts after a malfunction has been isolated to a particular stage of equipment.

Prescribe a sequence of checks such that the malfunction is first isolated to a single series chain.

The best check to make first in isolating the trouble to a particular chain is at the terminal output of the chain where the probability of observing the malfunction in that check, divided by the time required to make the check is a maximum.[1]

Once a malfunction has been isolated to a single chain, the best order is to check at the point in the chain where the probability of observing a malfunction is closest to one half.[2] The order is affected, however, by the time required to make the various checks. It may be desirable to make the least time-consuming checks first even though they may not adhere to the principle of one-half probability as given above. It may also be desirable to delay checks of components in feedback loops if the time required to break the loop for checking is appreciable.

---

1. Three considerations are relevant here:
   a. The "series chain" may have a number of branches contributing to its final output.
   b. The probability of the malfunction being in a given chain may be determined from data on the frequency of malfunctions, or may be based simply upon the number of components in the chain.
   c. The time required to perform certain checks may have to be estimated.

2. For a detailed rationale and mathematical proof, see:
   Miller, R. B., Folley, J. D., Jr., and Smith, P. R. (Reference 5)

Provide the technician with appropriate data flow diagrams *and* a table for each symptom pattern giving the most efficient sequence of checks.

The table shown below provides for a flexible order of checks which depends upon whether or not an out-of-tolerance indication is obtained at each point. "A" represents the *first* check that should be made if a given symptom pattern is observed. "B" and "C" are alternative checks following "A", and so on.

Flexible Check Sequence Table

Choose the next alternative to the *left* following an out-of-tolerance indication, and the one to the *right* following an in-tolerance indication.

Out-of-tolerance ← → In-tolerance

A							
B				C			
D		E		F		G	
H	I	J	K	L	M	N	O
etc.		etc.		etc.		etc.	

Recommended Characteristics for Presentation of Job Instructions and Information

IMPORTANCE OF GOOD PRESENTATION

Instructions and information which are hard to follow will not be widely used in the field. Poor presentations also increase the chances of error in performing specified operations. Ineffective presentations can offset the effects of otherwise good design for maintainability.

KINDS OF PRESENTATION MOST SUITABLE FOR VARIOUS PURPOSES

Purpose	Kind of Presentation
Describing procedures in detail	Step-by-step instructions
Describing procedures for experienced technicians	Checklists
Presenting physical features	Drawings and Photographs
Presenting large amounts of data	Tables and Charts
Describing processes or interrelationships	Diagrams

Presentation of maintenance job information or instructions in paragraph form should be avoided. This format tends to obscure the step-by-step nature of procedures, and requires many words where other formats require few.

CONTENT OF JOB INSTRUCTIONS

Instructions should contain only job-relevant information. Handbooks of maintenance instructions have frequently contained much information which was of very limited help to the technician in doing his job.

Instructions must be prepared specifically for each level of maintenance rather than the instructions for all levels being combined into a single set.

Nomenclature used on the equipment should be used on job instructions. In cases where labels on the equipment are particularly cryptic, the complete nomenclature can also be given in the job instructions to clarify the label. For example: PWR SW (Master Power Switch).

Job instructions should present the required signal characteristics and tolerances for each test point.

If signal characteristics are not given the technician will waste time figuring out what the signal should be or, more likely, measuring the signal on a properly functioning piece of equipment. If he cannot do either, the value of the procedure and the test point is lost.

Job instructions should be fully indexed. The index should contain words the technician is likely to look for in locating a particular item in the instructions.

Stock numbers needed for ordering replacement components should be presented with all parts lists.

It has sometimes been the practice to list nomenclature and manufacturers' parts numbers but not to list Air Force stock numbers. This has meant that technicians wasted time referring to a separate parts list if one was available. If there was no such parts list, considerable difficulty was experienced in ordering replacement components.

All information in the instructions should be accurate. This seems almost too obvious to mention. Yet, technicians have reported that technical orders have contained numerous errors. This suggests that careful editing is required by persons familiar with design of the equipment. Even a single error in job instructions may cause considerable wasted maintenance time and may even result in malfunctioning equipment being passed as operating in tolerance.

PHYSICAL CHARACTERISTICS

Job instructions and diagrams which will be used continually will last longer if they are enclosed in plastic. This also permits the tecnnician to make notes and erase what he has written after completion of the task, without damage to the materials.

Fold-out pages in manuals should be:

1. Kept to a minimum.
2. Placed at the rear of manuals.
3. Readable with the manual opened to another place (by leaving blank the part of the sheet that is covered by other pages).

Line maintenance manuals should:

1. Have maximum dimensions of 5 1/2 x 8 1/2 inches and be no more than 1 1/2 inches thick so they will fit into a technician's coverall pocket.
2. Be bound so that they will lie flat when opened.
3. Contain simple, straight type that has good readability under poor light.

Printing of diagrams inside the covers of units is desirable if few modifications are anticipated. When modifications are made, correction sheets must be supplied to be pasted over the printed diagrams.

Attaching job instructions to auxiliary equipment is sometimes desirable. For example, a test set used only for aligning a particular computer could have a roll chart on the front panel which gives specific instructions for making the alignment.

When roll charts are used for presenting procedures, three steps of the procedure should be visible through the viewing window at one time. This is particularly important when warnings may be included in various steps. The middle step should be emphasized by lines painted on the viewing window.

REVISION AND AVAILABILITY

Job instructions should be kept current with modifications of the equipment. This is especially important when power voltages and/or signal characteristics change from one model to the next.

Whenever new models of an equipment are introduced into the field, old job instructions should not be rescinded until all old models are withdrawn from use.

There should be some clear way to identify for which model of an equipment a particular set of job instructions is appropriate.

Job instructions should be available when technicians are first assigned to maintain a particular equipment. Technicians have reported delays of up to two years between the time they were assigned to maintain an equipment and the time job instructions became available. Effectiveness of maintenance activities is quite limited when job instructions are not available.

STEP-BY-STEP JOB INSTRUCTIONS

This type of job instruction is well suited to maintenance tasks since it is set up for a sequence of steps. Each procedure can be divided into a series of steps and each step broken into a number of elements.

A format similar to the one in the following sample is strongly recommended for the presentation of procedural job instructions.

Step No.	Component	Action	Indication[1]	Remarks
2.1	Antenna Assy.	Mount azimuth and elevation protractors		See Drawing P
2.2	Set controls on on pilot's control box:	Set to:	Antenna travel on protractors is:	
	Operation Sw.	Auto-Search		
	Antenna-Az. Sw.	Center-Narrow	Az: ±23 1/2°	Adjust with Pot. P2371
	Antenna-El.Con.	Center	El: ±2 1/2°	Adjust with Pot. P2346
	Pulse Length Sw.	Long		
2.3	Antenna-Az. Sw. Antenna-El. Con.	Center-broad Full clockwise	Antenna travel on proctractors is: Az. ±67° El. +30° +25°	Same as 2.2

1. This is the particular aspect of equipment performance which the technician should note.

CHECKLISTS

This less detailed form of instructions is especially useful to more experienced technicians. The division of procedural steps into elements is eliminated and the goal of each step presented as a reminder to the technician.

Line technicians are particularly likely to find checklists helpful because they often must work in places where detailed instructions are inconvenient to use. It has been observed in the field that line technicians quite commonly have abstracted checklist material from Technical Orders and transcribed it onto pocket-sized notebooks. It would seem much more desirable for the designer to provide standardized checklist instructions for line technicians.

A format similar to the one in the following sample is strongly recommended for checklists.

Step No.	Action	Indication	Technician's Remarks
2.1	Mount protractors on antenna		✓
2.2	Set for narrow scan center	Az: $\pm 23\ 1/2^{\circ}$ El: $\pm 2\ 1/2^{\circ}$	No vertical scan O.K.
2.3	Set for broad scan center	Az: $\pm 67^{\circ}$ El: $+30^{\circ}$ -25°	No vertical scan O.K.

DRAWINGS AND PHOTOGRAPHS

These two pictorial presentations of information can be very valuable for supplementing written job instructions. Generally speaking, good quality drawings will probably be at least as effective as photographs for this purpose. Photographs frequently contain too much detail, thereby obscuring the particular item they are illustrating. On the other hand, photographs with irrelevant details blanked out and relevant details clearly shown may be very effective.

Drawings illustrating job instructions should include only the details needed for the illustration. Extraneous detail in such drawings tends to obscure the point.

The purpose of including drawings in job instructions should be either to clarify written instructions or to provide information the technician needs for maintenance operations. Drawings inserted only for humor or aesthetic reasons probably add little to the value of the instructions.

TABLES AND CHARTS

Tables are probably the most efficient way to present large amounts of data. Whenever similar information is to be presented concerning a number of different equipment components, tables may be particularly useful. In order for tables to be maximally useful, however, the maintenance job instructions should specify when and how each table should be used.

The information included in tables should be directly usable by the technician, without his having to make any data transformations. Engineering test data, for example, is likely to be of little use to the technician, while this same basic information translated into indications he should observe in the equipment may be indispensable to effective maintenance.

RECOMMENDED GENERAL CHARACTERISTICS FOR MAINTENANCE DIAGRAMS

Diagrams should reflect equipment unitization. For example, the "building block" of the line maintenance diagram should be the line replaceable unit. The value of unitized equipment will be severely reduced if this recommendation is not followed.

All of a particular circuit or loop should be on one page insofar as possible.

> Exception: Where trouble shooting is within a particular unit and the circuit runs from that unit to another unit and then returns, it may be desirable to present on a single page only the portion of the circuit which is within the suspected unit.

Diagrams for line technicians should be about 5 1/2 x 8 1/2 inches, since this size will fit easily into the standard work uniform pocket.

> Exception: Facilities for using large diagrams for line maintenance of certain ground equipments may be quite good.

Facilities for using large diagrams (e.g., 18" x 24") are usually adequate in shops and depots. Special stands or other provisions might make use of large size diagrams more convenient.

Fold-over, map-board, and roll-chart types of stands are all convenient for large diagrams in shops and depots. Diagrams on fold-over stands should probably be plastic coated to protect the diagram and to permit the technician to make notes which can easily be wiped off. A plastic plate on the front of a roll chart will serve the same purpose. Diagrams on map-board type stands should be printed on a durable clothlike material.

The same type of diagrams should be used for all subsystems and units of the equipment. It should be possible to trace signals from diagrams for one unit or subsystem to diagrams for another unit or subsystem.

Where signals are shown entering or leaving on a page, the component of the equipment from which it comes or to which it goes should be indicated. The page on which the signal can be picked up again for tracing should also be given.

A table of contents and index of diagrams should be given.

Color may be used to advantage on diagrams to code test points, types of signal flow, and classes of components. Color codes should be the same as used on the equipment and should be consistent for all diagrams.

DATA FLOW DIAGRAMS[1]

Data flow diagrams are given special consideration here because, although they are not yet in general use, they are the type judged to have the most potential value for maintenance.

Data flow diagrams should be prepared specially for use in maintenance and should contain only information needed to perform specified maintenance activities.

Components should be shown in the same relative position as in the equipment to extent that this is practical.

1. Sample data flow diagrams are shown on pp. 154, 155, and 156.

Components should not be pictured or schematized; only enough information should be presented to identify them. Chief emphasis should be given to the nature of the signal flow between components, particularly at points where "power on" checks can be made. Data flow diagrams should be concerned only with the electrical characteristics of the signal, not with the electrical characteristics of components.

Flow of fixed voltage supplied to components may be indicated in special color or even omitted from the diagram completely. If the latter is the case, information concerning these voltage supplies should be presented on a separate diagram or in table form.

The appearance of data flow diagrams is similar whether they deal with data flow among major components, assemblies, or subassemblies. A diagram of data flow among parts may look like a combination of a schematic and a wiring diagram.

Data flow diagrams should be based on a particular configuration of control settings for the prime equipment and/or test equipment. They may also be based on certain manually induced special conditions such as broken feedback loops or servos set to a particular position. The control settings and special conditions should be indicated on the diagram.

The electrical characteristics of the signal to be checked at each test point should be shown on the data flow diagram. When it is necessary to check complex time and shape characteristics of the signal, the required information may be keyed to tables at the edge of the diagram or to separate pages.

No information should be given about the nature of signal flow within units which are replaceable or throwaway at the level of maintenance for which the diagram was prepared.

Examples of Checking and Trouble-Shooting Aids

The following sample items illustrate some of the ideas presented on pages 131 to 147. An attempt has been made in preparing these samples to make them only complete enough to illustrate their characteristics and interrelationships. A complete set for a weapon system would, of course, be much more comprehensive.

SAMPLES PRESENTED

Block Diagram	provides a standard layout for components for use in data flow diagrams.
Outline of Preflight Check	outlines the standard check procedure.
Symptom Pattern Table	indicates what action to take for each symptom pattern.
Data Flow Diagram (line level)	shows functional interconnections of line replaceable units and trouble-shooting steps for one symptom pattern.
Data Flow Diagram (shop level)	shows functional interconnections of shop replaceable units and trouble-shooting steps for one line replaceable unit.
Data Flow Diagram (shop or depot level)	shows functional interconnections of electronic parts for one shop replaceable unit.

Steps in Using These Materials for Trouble Shooting

1. Perform all steps in Section 1 of Preflight Check.

   If no malfunctions noted, perform Section 2, etc.

   If malfunction symptoms are observed, refer to Symptom Pattern Table.

2. Locate on the Symptom Pattern Table the pattern that was observed in the Preflight Check. From the Table determine which unit to replace or which line maintenance data flow diagram to use in making further checks.

3. Refer to the appropriate data flow diagram. From this diagram determine what special checks to make to isolate the malfunction.

4. Replace the malfunctioning line replaceable unit as identified through the special checks.

   At this point the shop or depot would usually take over, performing the following steps.

5. Refer to the shop maintenance data flow diagram for the replaced unit.

6. Perform the standard check-out procedure for that unit. Follow a trouble-shooting procedure similar to that in steps 2 - 4 above, using the appropriate diagrams for the unit in question.

CONSIDERATIONS IN DESIGN AND USE OF THESE MATERIALS

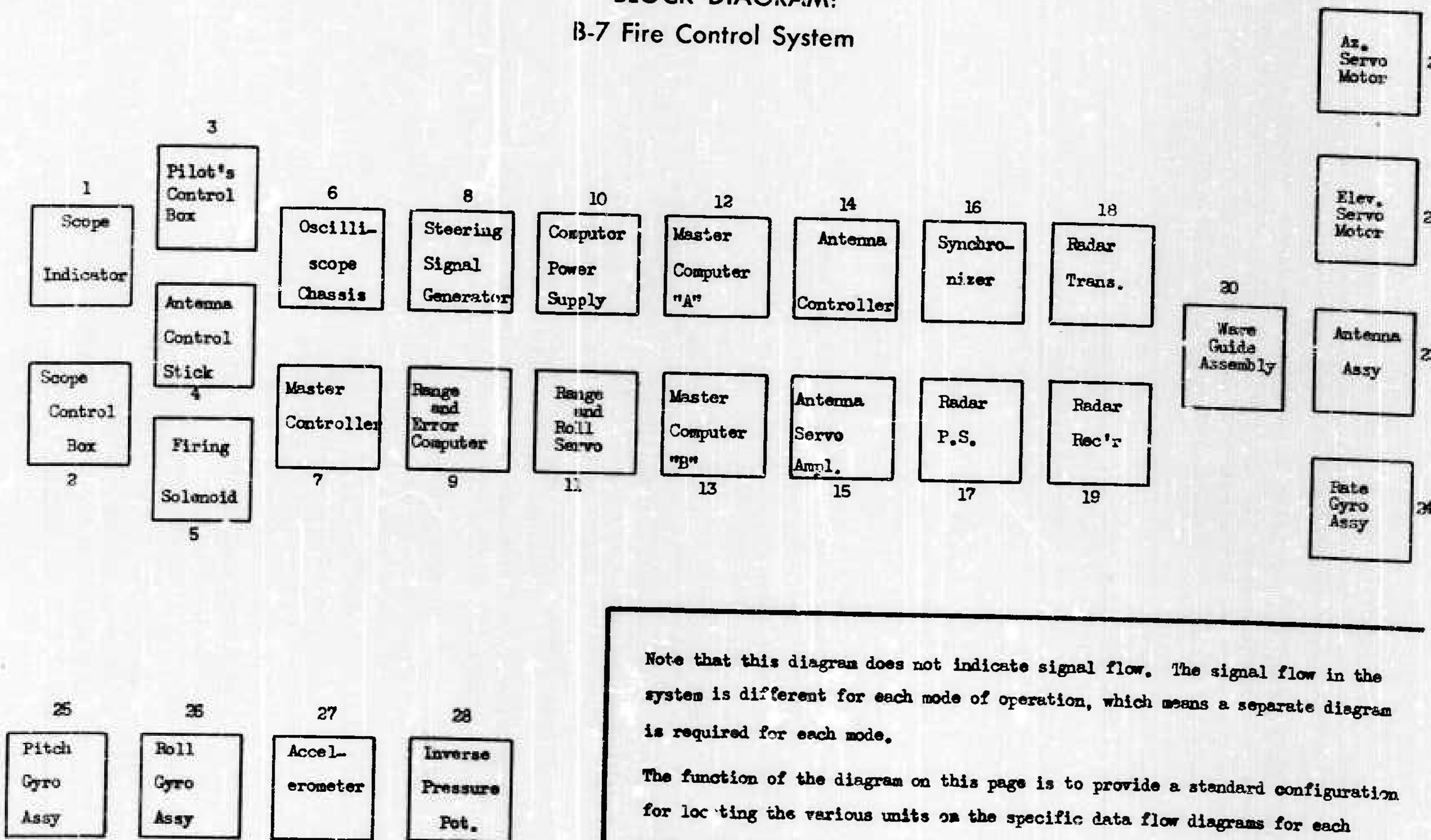
Note that the line level Data Flow Diagram shows only signals. It does not show power voltage inputs to the various components. When a malfunction has been isolated to a single replaceable or repairable component on the basis of signal flow checks, it is probably desirable to check all power voltage inputs for that component before replacement. The in-tolerance values for these power voltages should probably be presented in a separate table.

Preparation of tables of symptom patterns for trouble shooting to electronic parts (resistors, condensers, etc.) may be unfeasible. This is because of the large number of components involved in all of the line replaceable units and the fact that three kinds of measures - AC Voltage, DC Voltage, and resistance - can usually be taken conveniently at each test point.

It seems quite likely that an inflexible check sequence would be useful for trouble shooting to parts. Such a sequence should probably begin with tube checking. The three kinds of measurements might be used most effectively at different phases of the trouble shooting within an assembly. For example, the signal voltage might first be checked to narrow the trouble to a stage or group of stages. The DC voltages can further narrow the trouble to a few components in the stage or group of stages. Finally, resistance measures taken in a specified, systematic order could narrow the trouble to a particular component of the circuit.

The most important point is that a procedure should be prepared for trouble shooting even at this detailed level. This trouble-shooting procedure should adhere, insofar as possible, to the suggestions presented earlier for a good trouble-shooting procedure.

BLOCK DIAGRAM:
B-7 Fire Control System



Note that this diagram does not indicate signal flow. The signal flow in the system is different for each mode of operation, which means a separate diagram is required for each mode.

The function of the diagram on this page is to provide a standard configuration for locating the various units on the specific data flow diagrams for each mode. This configuration should be used for all data flow diagrams. (See sample on p. 154.)

PREFLIGHT CHECK, OUTLINE OF STEPS:
B-7 Fire Control System

Note: This example is presented only to show how a routine check can be used in designing aids for systematic trouble shooting. It only outlines the steps of the check very briefly. It is not intended to illustrate either a detailed job instruction form or a check list.

1. Radar Set Check
   - 1.1 Power Supply Check
     - 1.1.1 +300V DC Regulated Voltage
     - 1.1.2 +150V DC Regulated Voltage
     - 1.1.3 -150V DC Regulated Voltage
     - 1.1.4 Repeller Voltage
     - 1.1.5 AC Power Bus
     - 1.1.6 Relay Supply DC Voltage
   - 1.2 Transmitter Output Checks
     - 1.2.1 Frequency Check and Adjustment
     - 1.2.2 Inspect Frequency Spectrum
     - 1.2.3 PRF Check
     - 1.2.4 Inspect Shape of Modulation Envelope
     - 1.2.5 Power Output Check
   - 1.3 Receiver Test
     - 1.3.1 Sensitivity Check
     - 1.3.2 Receiver Output Check
     - 1.3.3 AFC Check

2. Search Mode Operational Check
   - 2.1 Antenna Search Pattern Check
     - 2.1.1 Narrow Pattern Check (right and left)
     - 2.1.2 Wide Pattern Check (center)
     - 2.1.3 Check Antenna Spin Pattern
   - 2.2 Display Calibration
   - 2.3 Artificial Horizon Check

3. Manual Track Operational Check
   - 3.1 Antenna Control Check
   - 3.2 Manual Track Test
   - 3.3 Lock-on Check
     - 3.3.1 Sensitivity of Lock On
     - 3.3.2 Check Display Function

4. Auto Track Operational Check
   - 4.1 Attack Phase Operational Check
   - 4.2 Rocketfire Check
   - 4.3 Pull Out Warning Check

5. Miscellaneous Checks
   - 5.1 Check Antenna Table Dither
   - 5.2 Check Radar Anti-Jam Control Operation
   - 5.3 Check Pilot's Scope Controls

TABLE OF SYMPTOM PATTERNS OBTAINABLE FROM PREFLIGHT CHECK:

B-7 Fire Control System

(Patterns not shown in this table will probably never occur.)

X = Malfunction symptom observed
LRU = Line Replaceable Unit
0 = In-tolerance indication obtained

Pattern

1.1	1.2	1.3	
X	0	0	Do not run test 1.2 and 1.3 until power supply is adjusted correctly or replaced
0	X	0	Use data flow diagram 1.a for trouble shooting
0	0	X	Use data flow diagram 1.b for trouble shooting
0	X	X	Use data flow diagram 1.c for trouble shooting

2.1	2.2	2.3	
X	0	0	Use data flow diagram 2.a for trouble shooting
0	X	0	Use data flow diagram 2.b for trouble shooting
0	0	X	Use data flow diagram 2.c for trouble shooting
X	X	0	Replace master controller (LRU 7)
0	X	X	Use data flow diagram 2.d for trouble shooting
X	0	X	Replace master controller (LRU 7)
X	X	X	Replace master controller (LRU 7)

3.1	3.2	3.3	
X	0	0	Use data flow diagram 3.a for trouble shooting
0	0	X	Use data flow diagram 3.b for trouble shooting
X	X	0	Replace master controller (LRU 7)
0	X	X	Use data flow diagram 3.c for trouble shooting
X	0	X	Use data flow diagram 3.d for trouble shooting
X	X	X	Use data flow diagram 3.e for trouble shooting

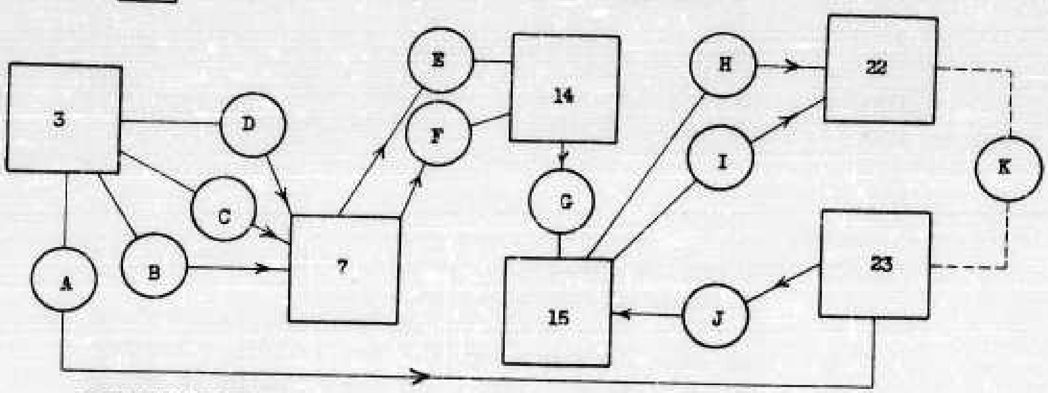
4.1	4.2	4.3	
X	0	0	Use data flow diagram 4.a for trouble shooting
0	X	0	Use data flow diagram 4.b for trouble shooting
0	0	X	Use data flow diagram 4.c for trouble shooting
X	0	X	Use data flow diagram 4.d for trouble shooting
0	X	X	Replace master computer "B" (LRU 13)
X	X	X	Use data flow diagram 4.e for trouble shooting

5.1	5.2	5.3	
X	0	0	Use data flow diagram 5.a for trouble shooting
0	X	0	Use data flow diagram 5.b for trouble shooting
0	0	X	Use data flow diagram 5.c for trouble shooting
X	X	X	Check for voltage at main power bus. If this checks OK replace pilot's control box (LRU 3)

Data Flow Diagram (line level) B-7 Fire Control System

Symptom Pattern 2.a (2.1:X, 2.2:0, 2.3:0, Azimuth Traverse OK)

☐ = line replaceable unit ○ = test point



PRELIMINARY SETTINGS

On pilot's control box

Power sw . . . . . ON
Operations sw . . AUTO-SEARCH
Antenna az. sw . . CENTER - NARROW
Antenna el. sw . . CENTER
Pulse sw . . . . . LONG

TEST POINT	CORRECT READING
A	+300 VDC
B-F	Continuity
G	±130V
H to I	+250 VDC
J	+150 VDC
K	Motor 22 operates

CHECK INFORMATION

Voltage and continuity checks

1. Use VM 811
2. Tolerance ±5V

Wave shape checks

1. Use KS 339 scope
2. Signals thru DC amplifier
3. Internal sweep 3 CPS
4. Wave shape not critical
5. Absence of signal or spurious oscillations indicate malfunction
6. Asymmetry about zero axis requires adjustment. See Task Instruction form 2.1

DIRECTIONS FOR SPECIAL CHECKS

1. Make checks on top line first.
2. If all are in tolerance, make checks in box immediately below and to the right. If any check is out of tolerance, make checks in box immediately below to the left.
3. Continue working down the table until you come to a number.
4. Replace the unit whose number you come to.

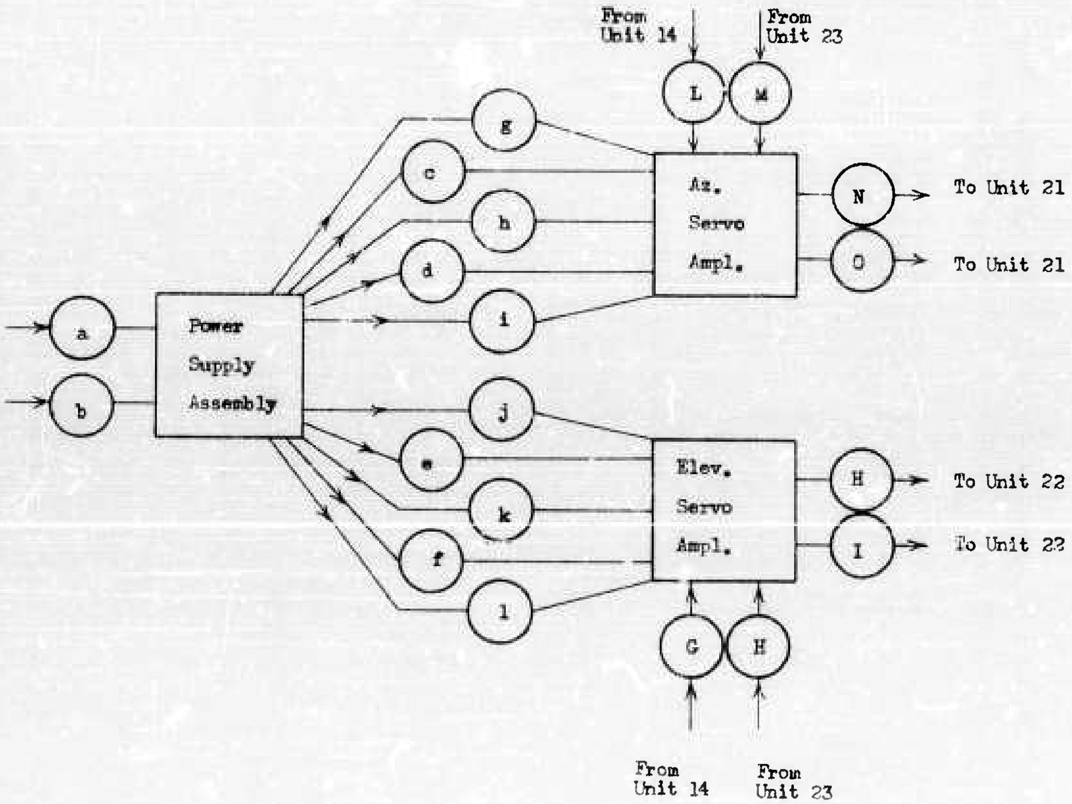
Out-of-tolerance ← → In-tolerance

<table>
<tr><td colspan="8">G</td></tr>
<tr><td colspan="3">B, C, & D</td><td colspan="5">K*</td></tr>
<tr><td>3</td><td colspan="2">E & F</td><td colspan="4">J</td><td>23</td></tr>
<tr><td></td><td>7</td><td>14</td><td colspan="2">A</td><td colspan="2">H to I</td><td></td></tr>
<tr><td></td><td></td><td></td><td>3</td><td>23**</td><td>15</td><td>22</td><td></td></tr>
</table>

* Prior to check K remove motor from mount but do not open electrical connections. Move antenna platform manually to positive elevation angle stop.

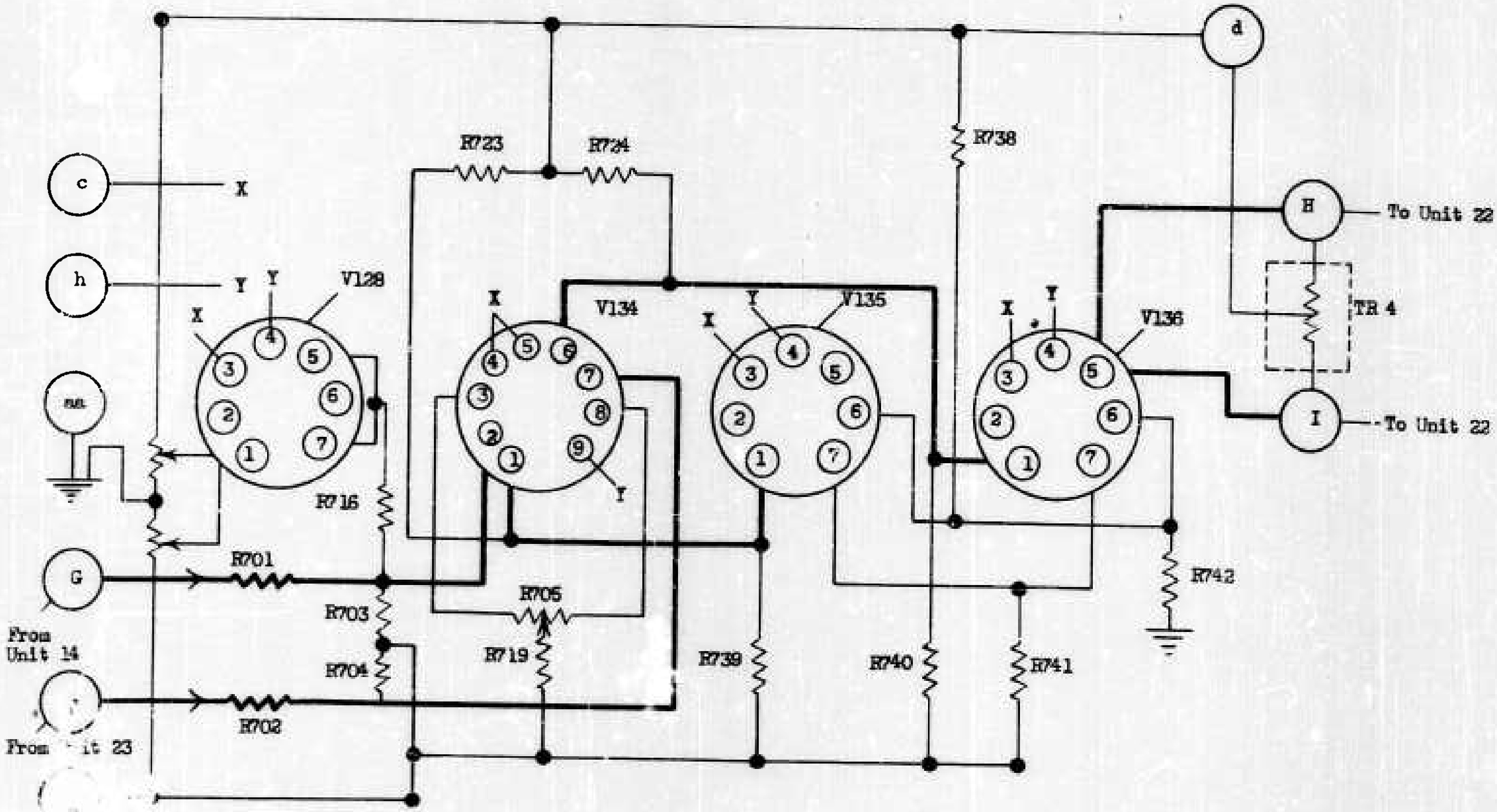
** Only the follow-up pots in this unit need to be replaced at this point.

Data Flow Diagram (shop level) B-7 Fire Control System
Antenna Servo Amplifier Unit - Line Replaceable Unit 15



Tables of in-tolerance check readings, setup for the equipment, and best order for making checks could be presented for this diagram in the same manner as they were for the diagram on the previous page.

Data Flow Diagram (shop or depot) B-7 Fire Control System Elevation Servo Amplifier Assembly of Line Replaceable Unit 15



Note: ... bench checks are made on this amplifier install simulated load resistor unit TR 4.

A pr... re can be prepared ... trouble shooting this circuit similar to the procedure suggested for trouble ...ting to line replaceable units, ... that sequence of c... s can be specified which will isolate the trouble to a single ... ent.

Glossary

adjusting - bringing an out-of-tolerance condition into tolerance by manipulating equipment controls.

assembly - a combination of parts or subassembly that may be taken apart without destruction, which has no application or use of its own but is essential for the completeness of a more complex item with which it is combined. (From ARDC Man. 80-4)

automatic test equipment - checks two or more signals without the intervention of a technician. The test usually stops when the first out-of-tolerance signal is detected.

breadboard model - an assembly of preliminary circuits and parts to prove the feasibility of a device, circuits, equipment, system or principle in rough or breadboard form, without regard to the eventual over-all design or form of parts. (From MIL-STD-243)

built-in test equipment - is an integral part of the prime equipment. It may be a complex automatic checker or a simple voltmeter with external leads.

checking - sampling signals for malfunction symptoms by comparing an observed signal with a standard signal.

collating test equipment - presents the results of two or more checks as a single display. For example, a light may come on only if a number of different signals are in tolerance.

component - a combination of parts, assemblies, accessories, and attachments, which together form an equipment to accomplish a specific complete function. (From ARDC Man. 80-4)

depot maintenance - maintenance performed on equipment removed from its operational site or base.

designer - any person who has a significant influence on design and/or development of a system.

developmental model - a model designed to meet performance requirements of the specification or to establish technical requirements for production equipment. This model need not have the required final form or necessarily contain parts of final design. It may be used to demonstrate the reproducibility of the equipment. (From MIL-STD-243)

experimental model - a model of the complete equipment to demonstrate the technical soundness of the basic idea. This model need not have the required final form or necessarily contain parts of final design. (From MIL-STD-243)

field maintenance - see shop maintenance.

go, no-go test equipment - provides only one of two alternative answers to any question. It tells only whether a given signal is in or out of tolerance.

human engineering - the scientific study of human capabilities and limitations and application of the resulting knowledge to system design.

inspecting - looking for physical damage, listening for unsatisfactory operation, smelling for odors associated with malfunction such as leaking fluids and burning insulation, and feeling for abnormal temperature or vibration.

line (organizational) maintenance - maintenance performed on equipment while it is installed in its normal operating position.

maintainability - a function of the rapidity and ease with which maintenance operations can be performed to avert malfunctions or correct them if they occur.

maintainability support - any item which contributes to the effective maintenance of prime equipment. Procedures, training, personnel, and equipment all may be maintainability supports.

organizational maintenance - see line maintenance.

periodic maintenance - maintenance performed on equipment on the basis of hours of operation or calendar time elapsed since last inspection.

preproduction model - see prototype model.

prime equipment - an assemblage of mechanical and/or electrical components having a primary purpose other than maintenance of other equipment. Prime equipment and the men and machines required to supply, operate, and maintain it are commonly called a system.

production model - a model in its final mechanical and electrical form of final production design made by production tools, jigs, fixtures and methods. (From MIL-STD-243)

prototype (preproduction) model - a model suitable for complete evaluation of mechanical and electrical form, design and performance. It shall be of final mechanical and electrical form, employ approved parts and be completely representative of final equipment. (From MIL-STD-243)

reliability - the probability that a product will give satisfactory performance for a given period of time when used in the manner and for the purpose intended.

repairing - correcting a malfunction by mending broken parts or connections.

replacing - substituting one unit for another, identical unit. Usually done to substitute a properly functioning unit for a malfunctioning unit.

service test model - a model to be used for test under service conditions for evaluation of suitability and performance. It shall closely approximate the final design, have the required form, and employ approved parts or their interchangeable equivalents. (From MIL-STD-243) servicing - cleaning, charging, and lubricating the system and regular changing of filters, desiccators, etc.

shop (field) maintenance - maintenance performed at the operational base or site, on equipment which is removed from installation.

subsystem - a breakdown of the first order of a system into its assemblies and subassemblies. (From ARDC Man. 80-4)

system - see weapon system.

trouble shooting - determining which unit or part is malfunctioning.

unit - any combination of parts which can be removed from a subsystem without destruction. A unit may be a component, assembly, or subassembly.

weapon system - equipment, skills, and techniques, the composite of which forms an instrument of combat, usually but not necessarily, having an air vehicle as its major operational element. The complete weapon system includes all related equipment, materials, services, and personnel required solely for the operation of the air vehicle, or other major element of the system, so that the instrument of combat becomes a self-sufficient unit of striking power in its intended operational environment. (From ARDC Man. 80-4)

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